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The Quality and Yield of Tobacco as Influenced by Manurial and other Operations

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THE QUALITY AND YIELD OF TOBACCO AS INFLUENCED BY MANURIAL AND OTHER OPERATIONS.

BY

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I. Introduction.

Ordinary tobacco (*Nicotiana Tabacum*) is extensively cultivated throughout India. The area [1] occupied by the crop is estimated at 1,101,000 acres, of which 120,300 acres are under cultivation in Bihar and Orissa alone. The value of the crop is over 150 million rupees which would bring tobacco into sixth position of importance among the crops in India.

India stands second among the tobacco-growing countries of the world as regards the quantity of the crop produced, the first in order of production being the United States of America. Though tobacco is one of the principal crops of India, the quality is somewhat inferior and the market price of the product is considerably lower than that of most of other countries.

Howard and Howard [2] have made a study of the tobacco crop in India and have suggested a number of improved methods of growing this crop (the raising of its seedlings, its planting, its cultivation, etc.) suitable to local conditions. The present publication, however, deals with the subject of Indian tobacco from a chemcial standpoint. The objects of the investigation are considered under the following three heads :—

(1) A study of the effect of a variety of manures and fertilizers on the yield, quality and nicotine content of tobacco plants.

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[1] *Agri. Stat. of India,* 1919 20, Vol. I.
[2] *Agri. Res. Inst. Pusa, Bull* 50.

(2) A comparative study of the effect of such operations as "topping" and "spiking" on the yield and quality of tobacco plants.
(3) A comparative study of the changes occurring during the process of curing by the ordinary country method and by the so-called "rack-curing" method.

At present most of the information which is available on these points is to be found in publications issued by the Agricultural Bureau in America or by Landw. Versuchs station. As, however, Indian climatic conditions and soils are so widely divergent from those found in the countries referred to, the results arrived at will require careful checking by experiments made in India before they can be employed with any confidence here. In Bihar, the most extensive cultivation as well as the best tobacco comes from Tajpur Sub-division in Pergannah Sareysa, and Pusa being situated in the same Sub-division (Tajpur), the conditions there are favourable for carrying out such an investigation.

II. The Effect of Manures and Fertilizers on the Yield, Quality and Nicotine Content of Tobacco.

With a view to ascertain the effect of various manures and fertilizers on the yield, quality and nicotine content of tobacco, pot culture experiments and field trials were started in October 1916.

I. The effect on the yield.

The pot culture experiments consisted of eight sets of jars in duplicate, each set receiving different manurial treatment. All the jars were filled with the same amount of Pusa soil and constant moisture content was maintained alike in all the jars throughout the experiments. One set of jars was retained as a control and received no manure and the other sets had either farmyard manure, farm-yard manure in combination with superphosphate, superphosphate in conjunction with nitrate of soda, superphosphate mixed with saltpetre or superphosphate in combination with nitrate of soda and muriate of potash. In addition, there were two sets which received heavy doses of phosphatic and nitrogenous manures respectively in addition to a complete mineral manure.

Field trials were carried out at the same time as follows:—

An area of land about 30 ft. by 100 ft. was thoroughly cleaned of weeds and ploughed four times at intervals of about three weeks before it was divided into plots and tobacco seedlings transplanted in them. The area was divided into fourteen plots each 12 ft. by 15 ft. arranged in two

parallel rows, each row having seven plots. Each plot was separated from its neighbours by fallowed strips of about 3 ft. across.

Plan of fertilizer experiment on tobacco, 1916-17.

Plots	Fertilizing materials per acre	Fertilizing elements per acre		
		Phosphorus	Potassium	Nitrogen
		lb.	lb.	lb.
A & A_1	None	*nil*	*nil*	*nil.*
B & B_1	Farmyard manure 5 tons	..	..	40
C & C_1	Superphosphate containing 12 per cent soluble P_2O_5 5 cwt. ; saltpetre $2\frac{1}{4}$ cwt	30	110	40
D & D_1	Superphosphate 5 cwt ; nitrate of soda 2 cwt.	30	..	40
E & E_1	Superphosphate 5 cwt. ; nitrate of soda 2 cwt. ; muriate of potash $1\frac{1}{2}$ cwt.	30	75	40
F & F_1	Indigo *seeth* $2\frac{1}{2}$ tons	Not estimated	Not estimated	40

All the fourteen plots were manured on the same day and tobacco seedling which were about 4 inches high were transplanted next day in the afternoon. In each plot three varieties were sown ; they were—" Pusa Type 28 " in three lines having 15 plants, " Dhamakul " in one line having 5 plants and " Surujmukhi " in two lines having 10 plants.

So far as the general appearance of the plants in jars was concerned, those which had received an excess of 25 per cent. P_2O_5 over complete mineral manure were decidedly the best ; the second in order were those treated with superphosphate mixed with saltpetre and those treated with superphosphate in combination with nitrate of soda and muriate of potash ; the third in order were those treated with superphosphate mixed with nitrate of soda and those treated with farmyard manure in combination with nitrate of soda. Plants grown in jars which were kept unmanured were decidedly inferior to all.

Table I gives, in a tabular form, the total fresh weight and the total dry matter of tobacco plants grown in pots under different manurial treatments.

TABLE I.

Jar No.	Fresh weight of plants in grm.	Weight of leaves after being cured in grm.	Total dry matter in leaves and stems in grm.	Treatment of jars
1 & 2	1,350	230	242·4	No manure.
3 & 4	2,070	303	411·5	Superphosphate and nitrate of soda.
5 & 6	2,170	336	413·9	Superphosphate and saltpetre (pot. nitrate).
7 & 8	2,260	328	431·1	Superphosphate, nitrate of soda and muriate of potash (pot. chloride).
9 & 10	1,820	279	315·1	Farmyard manure.
11 & 12	1,825	264	332·2	Farmyard manure and superphosphate.
13 & 14	1,885	281	342	Farmyard manure and nitrate of soda.
15 & 16	2,695	351	459·3	Excess of 25 per cent superphosphate, superphosphate, nitrate of soda and muriate of potash.

An examination of this tabular statement shows that the "potassium" increased the yield to a certain extent and a heavy dose of phosphatic manure in addition to a complete mineral manure improved the yield to a great extent.

TABLE II.

Treatment of plots	Fresh wt. of tobacco crops in kilos per. plot	Total dry matter in kilos	Fresh wt. of crop calculated as yield per acre in kilos
No manure	15·540	2·923	3,822
Farmyard manure	19·795	3·613	4,872
Superphosphate and saltpetre	21·484	3·875	5,285
Superphosphate and nitrate of soda	18·488	3·616	4,547
Superphosphate, nitrate of soda and muriate of potash	20·871	3·856	5,133
Superphosphate and farmyard manure	21·469	3·935	5,281
Indigo *seeth*	20·249	3·657	4,984

Table II gives in a tabular form the results of field trials carried out same year (1916-17) with different manures and fertilizers. A complete mineral manure consisting of superphosphate, nitrate of soda and muriate of potash increased the yield by 34 per cent., superphosphate with farmyard manure increased it by 36 per cent., indigo *seeth* by 30 per cent., and farmyard manure by 28 per cent. As in the case of pot experiments potassium always increased the yield to a certain extent and a complete mineral manure gave the best results, but considering the high cost of such a complete mineral manure as superphosphate, nitrate of soda and muriate of potash no worse results were obtained with indigo *seeth* or with farmyard manure which are so easily available in Bihar and which cost also less.

In the following year 1917 another set of field experiments were laid down. In 1916-17 the individual effect of the manurial ingredients, *e.g.*, P_2O_5, N. K, was not tested and consequently in 1917-18 the field experiments were designed to test this point. The plots were arranged similarly to those of the previous experiments, but this time the size of each plot was larger, being 14 ft. by 25 ft. each. In each plot two varieties of tobacco "Pusa Type 28" and "Surujmukhi" were grown.

Plan of fertilizer experiments on tobacco, 1917-18.

Plot	Fertilizing materials with rate of application per acre	Fertilizing elements per acre		
		Phosphorus	Potassium	Nitrogen
		lb	lb.	lb.
A & A_1	Superphosphate containing 20 per cent. soluble P_2O_5—2 cwt.	20	..	..
B & B_1	Superphosphate containing 20 per cent soluble P_2O_5—3 cwt.	30	..	..
C & C_1	None	..	..	..
D & D_1	Farmyard manure amount equivalent on P_2O_5 to 2 cwt. superphosphate per acre.	20	..	30
E & E_1	Superphosphate containing 20 per cent soluble P_2O_5—2cwt., and saltpetre—2½ cwt.	20	110	40
F & F_1	Saltpetre 2½ cwt.	..	110	40

The results of 1917-18 field trials showed that the individual effect of superphosphate or saltpetre on the yield of tobacco was almost negligible, whereas these two in combination increased the yield by about 16 per cent. Farmyard manure used singly gave a still better result, the yield being increased by about

30 per cent. The use of a heavier dressing (3 cwt. per acre) of superphosphate singly in no way improved the yield. The results obtained are tabulated in Table III.

TABLE III.

Treatment of plots	Fresh weight of tobacco crop in kilos per plot	Total dry matter in kilos	Fresh weight of plants calculated as yield per acre in kilos
Superphosphate at 2 cwt. per acre	41·85	8·015	5,231
Superphosphate at 3 cwt. per acre	41·40	7·938	5,175
No manure	41·00	7·898	5,125
Farmyard manure	53 10	9·400	6,637
Superphosphate and saltpetre	47·25	8·766	5,962
Saltpetre	42 97	8·113	5,371

Combining the results of experiments carried on in jars in 1916-17 and the field trials carried on in two consecutive years 1916-17 and 1917-18 the figures obtained would seem to justify the following inferences.

(1) As the fertilizer for tobacco in Pusa soil, superphosphate or saltpetre used singly is not effective.

(2) A complete mineral manure such as superphosphate, sodium nitrate and muriate of potash gives an excellent effect.

(3) The presence of potassium in the fertilizer has regularly increased the yield.

(4) It appears that the greatest total yield is produced by a fertilizer containing relatively more phosphorus in proportion to nitrogen than is found in ordinary farmyard manure (*vide* pot experiment, 1916-17, jars 15 and 16, and the field trails superphosphate and farmyard manure, 1916-17).

(5) As the fertilizer for tobacco, farmyard manure or indigo *seeth* occupies a leading position on account of their cheapness, their availability in Bihar and their great effectiveness.

The reason of the great effectiveness of farmyard manure or indigo *seeth* is quite obvious. Tobacco is a crop which will not grow well unless the soil is not loosened very frequently and the use of such organic manure as farmyard manure or indigo *seeth* makes the soil more porous. Bihar soil is generally poor in organic matter and the application of this constituent is attended with a good crop of tobacco.

2. The effect on the quality.

The quality of a tobacco depends on various properties such as burning qualities, size, weight, delicate structure, elasticity, colour and fermentative properties, and these in turn depend upon some of the chemical constituents of the tobacco plant. Fisca and Imai [1] deduce the following conclusions from their researches on the quality of tobacco :—" A high per cent. of nicotine has not been shown to be an indication of the good quality of tobacco. .... The albuminoids in a tobacco afford no indication of quality unless the proportion of amides is simultaneously considered. The amido nitrogen represents, for the most part, harmless, or perhaps even beneficial nitrogenous compounds. Any way the conversion of albuminoids into amides is one of the most important results of the fermentation......... Only considerable differences in the amount of the various constituents of tobacco can give any conclusive indication of the quality of a tobacco. Very bad tobacco always contains much albuminoid matter, sulphuric acid, chlorine and large quantities of mineral acids, with small proportion of amido nitrogen and potash." The various properties of tobacco just mentioned are more or less affected by the variety of tobacco, the soil, time and manner of manuring, manner of setting, treatment of the plant in the field, climate and time of harvesting. The properties of tobacco may also be materially affected by the manner of curing, the condition of the weather during drying and the fermentation itself. The fact that so many factors play a part in determining the quality of tobacco makes this subject an especially difficult one to study. In the experiments outlined above, other factors and condition of growth having been kept, as far as possible, the same, observations on the effect of different manurial treatments on the quality of tobacco were made.

Alexander Cserhati,[2] Harry Patterson,[3] Edward Jenkins,[4] MaxLehmann,[5] Rasmussen,[6] Adolf Mayer,[7] Nessler,[8] Johnson,[9] Fesca,[10] and Garner[11] carried out a series of experiments on the effect of different fertilizers and manures on the composition, quality and combustibility of tobacco. Since these experiments were carried out by different investigators at different places and under such varying conditions as soil, climate, etc., and since their conclusion are so varied, it seems, therefore, unreasonable to deduce any inference for one country from observations made in another of entirely different climate. The investigations of Adolf Mayer, Nessler, Fesca, Patterson and Garner seem to have shown beyond much doubt that potash

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1 *Jour. Soc. Chem. Industry*, vii, 759.
2 *J. Landev*, 1895, 43, 379-458.
3 *Marryland Stat. Bull.* 26, 57-92.
4 *Ann. Rep. Agri. Experi. Stat. Connecticut*, 1894 & 1896, 29, 322-333.
5 *Landw. Versuchs Stat.* 1903, 58, 439-470.
6 *Biochem Ztschr*, 69 (1915), No. 5-6, 461-466.
7 *Landw. Versuchs Stat.*, 38, 92-126.
8 ,, ,, ,, 90, 395-438.
9 *Connecticut Stat. Rep.* 1893, 112-127.
10 *Jour. Soc. Chem. Industry*, vii, 759.
11 *U. S. Dept. of Agri. Bureau of Plant Industry Bull.* 105.

is favourable to the glowing, that *chlorine* is unfavourable and that the effect of potash is most plainly seen when a part of the potash is in combination with organic acid, that is when the tobacco ash consists largely of bases with relatively low content of sulphates, chlorides and phosphates. Alexander Cserhati contradicts Nessler's statement that tobacco containing over 0·4 per cent. of chlorine with less than 2·5 per cent. of potash will not burn well, and declares that the view that cumbustibility of tobacco depends mainly on the amount of chlorine and potash it contains are erroneous. The opinions of these investigators with reference to the effect of fertilizers on organic constituents of tobacco, specially albuminoids, are much at variance.

In the present experiments the quality of the tobacco so far as physical texture of the leaf, colour, elasticity and size are concerned was determined by Mr. A. C. Acree, Director of the Indian Tobacco Development Company, Dalsing Sarai, to whom samples of tobacco grown under different manurial treatments were submitted. His report for the year 1916-17 runs as follows :—" The quality of the samples is good enough for cigarettes and we could use the whole lot just as they are if the tobacco was taken off of the stalks and graded. S-E, *i.e.*, Surujmukhi grown by superphosphate, sodium nitrate and potassium chloride, and S-F, *i.e.*, Surujmukhi grown by superphosphate and farmyard manure, are the best of the lot from a texture point of view, but the colour is a little dark. S-F, *i.e.*, Surujmukhi grown by superphosphate and farmyard manure, is the better of the two. D-D, *i.e.*, Dhamakul grown by superphosphate and sodium nitrate, and D-G, *i.e.*, Dhamakul grown by indigo *seeth*, are fairly good, but on the papery side, D-G, *i.e.* Dhamakul, grown by indigo *seeth*, would be very good if it had more body. The seven samples P-A to P-G, *i.e.*, seven samples of Pusa Type 28 grown by different manurial treatment, are just about the type we are buying here from the ryots. P-A, P-B, P-C and P-D, *i.e.*, Pusa Type 28 grown by either no manure or farmyard manure or superphosphate in conjunction with potassium nitrate or superphosphate with sodium nitrate, are all practically the same or so close I can tell no difference. P-E, *i.e.*, Pusa Type 28 grown by superphosphate, sodium nitrate and potassium chloride, and P-F, *i.e.*, Pusa Type 28, grown by superphosphate and the farmyard manure, while of the same type, are lacking in body and texture . P-G., *i.e.*, Pusa Type 28 grown by indigo *seeth*, is the commonest of the lot. P-G, *i.e.*, Pusa Type 28 grown by indigo *seeth*, and D-D, *i.e.*, Dhamakul grown by superphosphate and sodium nitrate, are very alike in quality and texture, and these are the worst samples of the lot." It may be pointed out that, whereas S-E, *i.e.*, Surujmukhi grown by superphosphate, nitrate of soda and muriate of potash, and S-F, *i.e.*, Surujmukhi grown by superphosphate and farmyard manure, have been reported as the best of the lot from a texture point of view, P-E and P-F, two samples of Pusa Type 28 grown respectively by the same manures and in the same plot as S-E and S-F, have been reported as lacking in body and texture. Again the samples P-A, P-B, P-C and P-D which were grown with no manure, farmyard manure, superphosphate with saltpetre, and superphosphate with nitrate of soda, respectively, have all been reported as alike in quality.

Samples of tobacco which were grown in 1917-18 under different manurial treatment were reported by Mr. Acree as follows :—" I have had a look at each of the samples separately and find that all of these samples will do for the manufacture of cigarettes :—

1. Surujmukhi grown by superphosphate at 2 cwt., superphosphate at 3 cwt., superphosphate with saltpetre	Good.
2. Surujmukhi grown by no manure, farmyard manure	Not so good.
3. Surujmukhi grown by saltpetre.	Common.
4. Surujmukhi duplicate grown by superphosphate at 2 cwt., superphosphate at 3 cwt., per acre	Fairly good.
5. Surujmukhi duplicate grown by no manure, superphosphate with saltpetre, saltpetre	Good.
6. Surujmukhi duplicate grown by farmyard manure	Very good.
7. Pusa 28 grown by superphosphate at 2 cwt. per acre	Very good.
8. Pusa 28 grown by superphosphate at 3 cwt., no manure, saltpetre .	Good.
9. Pusa 28 grown by farmyard manure, superphosphate with saltpetre .	Fairly good.
10. Pusa 28 duplicate grown by superphosphate at 2 cwt., superphosphate at 3 cwt., no manure, saltpetre	Good.
11. Pusa 28 duplicate grown by farmyard manure, superphosphate with saltpetre	Very good.

As in previous instances, so here too we find that Surujmukhi grown by superphosphate at 2 cwt. per acre and Surujmukhi grown by superphosphate at 3 cwt. per acre have been reported as " good," while their duplicate samples grown by the same manures under same condition have been reported as " fairly good." Again Pusa Type 28 grown by farmyard manure and Pusa Type 28 grown by superphosphate with saltpetre have been reported as " fairly good," while their duplicate samples grown by the same treatment and under same conditions have been reported as " very good." The facts prove beyond doubt that there is no definite relationship between the quality of tobacco (so far as texture, colour and body are concerned) and the different manurial treatments they receive. There does not appear to exist any constant relation even between the so-called quality of tobacco and the richness of the fertilizers used.

The samples of tobacco grown by different manurial treatments in the years 1916-17 and 1917-18 were analysed for their ash, potash, chlorine and protein contents *i.e.*, for constituents which have been generally recognized as affecting the quality of a tobacco. Table IV gives in a tabular form the analyses of the different samples of tobacco by different manurial treatments during 1916-17 and 1917-18. An examination of the figures in Table IV shows that the ash content has been hardly

affected by the different manurial treatments; the figures for ash content, in most cases, varied between short limits of 17 and 19·5 per cent. Similarly the protein contents or the ratios of amido nitrogen and albuminoid nitrogen to the total nitrogen have not been affected by the different treatment. For instance, superphosphate in case of Pusa Type 28 gave a comparatively high figure of 17·43 for amido nitrogen and a comparatively low figure of 43·9 for albuminoid nitrogen, while the same fertilizer gave in the case of "Surujmukhi" a comparatively low figure (in fact the lowest in the series) of 10·48 for amido nitrogen and a high figure (the highest in the series) of 60·76 for albuminoid nitrogen. Again a high figure for albuminoid nitrogen was obtained in one instance with superphosphate and saltpetre, while in another a lower figure was obtained with the same treatment. The potash in the tobacco, however, seems to be affected to some extent. Chemical fertilizers, in majority of cases, increased the potash content of tobacco, while organic manure as farmyard manure or indigo *seeth* with a very few exceptions gave a low potash content.

TABLE IV.

Treatment of plots	Pusa Type 28						Surujmukhi						Dhamakul		
	Pure ash %	Potash as K_2O %	Chlorine as Cl %	Total nitrogen %	Ratio of Amido nitrogen to total nitrogen	Ratio of Albuminoid nitrogen to total nitrogen	Pure ash %	Potash as K_2O %	Chlorine as Cl %	Total nitrogen %	Ratio of Amido nitrogen to total nitrogen	Ratio of Albuminoid nitrogen to total nitrogen	Pure ash %	Potash as K_2O %	Chlorine as Cl %
1. No manure	19·24	2·80	0·95	1·75	12·00	56·74	..	..	..	..	..	..	..	..	..
2. Farmyard manure . . .	18·58	2·49	0·48	1·90	12·63	51·90	..	..	..	..	..	..	..	..	..
3. Superphosphate and saltpetre .	18·75	2·80	0·34	2·05	13·66	53·27	..	..	..	..	..	..	17·16	3·14	0·16
4. Superphosphate and nitrate of soda	19·8	2·60	0·57	1·03	14·00	58·32	..	..	0·82	..	..	..	..	..	..
5. Superphosphate nitrate of soda and muriate of potash.	19·41	2·74	1·07	1·90	13·68	54·74	17·99	2·69	0·18	..	..	..	..	..	..
6. Superphosphate and Farmyard manure.	18·85	2·24	0·39	2·15	14·42	47·72	10·27	2·90	..	..	..	..	..	..	..
7. Indigo seeth . . .	20·51	2·24	0·77	1·78	12·36	57·42	..	..	..	..	..	.	16·58	2·21	0·61
8. Superphosphate at 2 cwt. per acre	·48	4·00	0·60	1·55	17·43	43·00	17·25	2·03	0·21	2·09	10·18	60·76	..	..	..
9. Superphosphate at 3 cwt. per acre	18·69	3·00	0·15	1·01	17·48	41·55	18·17	2·86	0·10	1·85	14·87	55·13	..	..	..
10. No manure	18·77	3·40	0·15	1·78	17·75	42·02	16·45	2·67	0·17	2·00	11·70	50·80	..	..	..
11. Farmyard manure . . .	17·20	2·20	0·24	2·10	15·57	51·00	17·62	3·31	0·69	1·68	10·00	50·35	..	..	..
12. Superphosphate and saltpetre		..		1·79	14·36	48·38	..	..	..	1·65	14·12	43·15	..	..	..
13. Saltpetre	..	..	..	1·96	13·72	51·80	..	..	..	1·81	15·03	52·49	..	..	..

Application of potassium chloride (muriate of potash) invariably increased the chlorine content which without doubt injures the burning capacities of tobacco. Addition of muriate of potash to superphosphate and nitrate of soda increased the chlorine content of tobacco by twice that which was obtained with superphosphate and nitrate of soda and by thrice that obtained with superphosphate and saltpetre. This fact was observed in the pot culture experiment of 1916-17, where tobacco from jars treated with superphosphate, nitrate of soda and muriate of potash gave the highest figure for chlorine.

In order to test the burning capacity or combustibility, tobacco samples which were grown by different manurial treatments in 1917-18 were sent to the Peninsular Tobacco Factory, Monghyr, where they were made into cigarettes of a particular length and diameter and as nearly as possible of the same compactness. The combustibility was tested by Toth's method[1] which enables one to numerically express the "combustibility" of a tobacco. The following figures were obtained, the value being the average of about six tests which were made with each samples.

Treatment of plot	Combustion value	
	Surujmukhi	Pusa Type 28
1. Superphosphate at 2 cwt., per acre	..	529
2. Superphosphate at 3 cwt per acre	710	..
3. No manure	527	525
4. Farmyard manure	558	516
5. Superphosphate and saltpetre	529	593
6. Saltpetre	467	445

There is little or no difference between samples grown by treatment 1, 3, 4 and 5 so far as combustibility is concerned. Saltpetre gave low value for both the varieties of tobacco tested, while a heavy dose of superphosphate (treatment 2) gave high combustion value. It was also observed that cigarettes made from tobacco which had been manured with saltpetre burnt quickly when smoked, whereas that receiving superphosphate burnt slowly and in some cases did not burn well when lighted. A combination of superphosphate with saltpetre produced a tobacco which burnt fairly well when smoked.

[1] *Rev. Internat. Falsi*, 1904, 17, 142-145.

Combining the results of two years experiments the following conclusions may be deducted :—

(1) The quality of tobacco so far as texture, colour, body, etc., are concerned bears neither any relation to the different manurial treatments it receives, nor to the richness of the fertilizers used.

(2) The ash, amido nitrogen and albuminoid nitrogen (constituents which have a bearing on the quality of tobacco) are hardly affected by different manurial treatments.

(3) Chemical fertilizers generally give a higher, and organic manure as farmyard manure or indigo *seeth*, a lower potash content (constituent which improves the burning quality of a tobacco).

(4) Application of muriate of potash (potassium chloride) as a fertilizer increases to a great extent chlorine content which injures the burning quality of a tobacco, other manurial treatments, having little or no effect on the chlorine content.

(5) Tobacco manured with saltpetre burns quickly when smoked, whereas that receiving superphosphate *burns* bad and slowly. A combination of these two manures produces tobacco which burns fairly well.

3. The effect on the nicotine content.

How far the nicotine content of a tobacco is affected by different manurial treatments and whether it bears any constant relation to the richness of the fertilizers used, has been the subject of investigation by a number of experimenters from time to time. Adolf Mayer[1] from a series of experiments on twelve one-fortieth acre plots, 11 being fertilized with various combinations of farmyard manure, nitrate of soda, caustic ammonia, superphosphate, Thomas slag, potash and double sulphate of potash and magnesia and one remaining unmanured, pointed out the influence of fertilizing materials on the quality of tobacco, and showed with reference to nicotine that its formation in the plant was favoured by a heavy application of easily available nitrogenous materials and that a high percentage of nicotine was in no case observed where the supply of plant food was deficient.

Jenkins[2] showed that the percentage of nicotine was above the average in tobacco to which large quantities of nitrogenous fertilizers had been applied. Passerine[3] found the percentage of nicotine in dry tobacco leaves from different plots as follows .—

Unfertilized plot 3·407 per cent., with 580 lb. dried blood per acre 2·533 per cent., with 267 lb. sulphate of ammonia 1·672 per cent., and with 356 lb. nitrate of soda 4·183 per cent. He thus concluded that there is no relation between the ni-

[1] *Landw. Versuchs Stat.* 38, 92-126.
[2] *Connecticut State Stat. Rep.*, 1896, 310-333.
[3] *Staz-Sper Agri. Ital*, 28 (1895), No. 8, 513-529.

cotine contents of tobacco and the manurial treatment they receive. Garner[1] concluded that the percentage of organic nitrogenous compounds including nicotine, is generally proportionate to the luxuriance and vigour of growth, and that conditions favourable to rank growth are brought about by the use of excessive quantities of nitrogenous fertilizers.

Rasmussen[2] from his studies with *Nicotiana rustica* and with Hungarian and Virginian varieties of tobacco showed that no clear and constant relation exist between the richness of the fertilizers used and the nicotine contents of tobacco plants.

In the present experiments, with a view to ascertain the effect of different manures and fertilizers on the nicotine content of tobacco, samples of tobacco grown in jars as well as in field during two years (1916-17 and 1917-18) were examined for their nicotine content. Table V gives the nicotine contents of tobacco grown in jars in 1916-17 with different manures and fertilizers and Table VI the nicotine content of tobacco grown in field during 1916-17 and 1917-18 with different manurial treatments.

TABLE V

No. of jars	Treatment of jars	Nicotine
1 and 2	No manure	5·12
3 and 4	Superphosphate and nitrate of soda	3·72
5 and 6	Superphosphate and saltpetre	5·02
7 and 8	Superphosphate, nitrate of soda and muriate of potash	4·67
9 and 10	Farmyard manure	5·11
11 and 12	Farmyard manure and superphosphate	3·67
13 and 14	Farmyard manure and nitrate of soda	3·78
15 and 16	Excess superphosphate with nitrate of soda and muriate of potash.	4·27

An examination of the figures in Table V will show that although tobacco grown in unfertilized jars and in jars treated with farmyard manures were decidedly very poor in size and weight, they gave high nicotine contents, whereas those grown in jars receiving superphosphate and nitrate of soda or superphosphate, nitrate of soda and muriate of potash with much better growth and yield gave comparatively low nicotine contents.

In Table VI, a column giving the fresh weight of tobacco crop yielded against the column for the nicotine content has been added. If we now examine the figures

[1] *U. S. Dept. of Agri. Bureau of Plant Industry, Bull.* 105.
[2] *Bichem. Ztschr.*, 69 (1915), 5-6, 461-466.

TABLE VI.

Year	Manurial treatment	Pusa Type 28			Surujmukhi		
		Nicotine per cent.	Fresh weight of crop in kilos	Kilos of leaves per kilo nicotine	Nicotine per cent.	Fresh weight of crop in kilos	Kilos of leaves per kilo nicotine
1916-17 .	No manure . . .	3·17	7·48	31·5	..	..	..
	Farmyard manure . .	3·90	10·18	25·6	..	..	..
	Indigo *seath* . . .	3·12	10·08	32·1	..	..	..
	Farmyard manure and superphosphate	4·15	9·79	41·5	..	..	..
	Superphosphate and saltpetre	3·93	10·63	25·4	..	..	..
	Superphosphate and nitrate of soda	3·65	8·32	27·4	..	..	..
	Superphosphate, nitrate of soda and muriate of potash	3·47	8·72	28·9	..	..	..
1917-18 .	No manure . . .	4·05	38·70	24·6	3·99	43·25	25·1
	Farmyard manure . .	4·06	55·26	24·6	3·27	40·72	29·9
	Superphosphate at 2 cwts. per acre	3·47	42·52	28·9	3·46	41·17	28·8
	Superphosphate at 3 cwts. per acre	3·82	42·66	25·7	3·21	40·15	31·1
	Saltpetre	3·90	14·60	25·6	3·41	41·40	29·3
	Superphosphate and saltpetre	3·86	48·42	25·9	4·05	46·08	24·7

for the nicotine content along with the figures for the yield, we find that in case of Pusa Type 28 as well as in case of Surujmukhi the nicotine yield is, in majority of cases, proportional to the yield of the crop or in other words to the growth of tobacco. On the other hand, we also find that in case of Pusa Type 28 indigo *seeth*, though giving as high a yield as farmyard manure, gives a very low nicotine content (the lowest in the series) and no manure though giving a very low yield (the lowest in the series) gives as high a nicotine content as farmyard manure giving the highest yield in the series. Such irregularities have been observed in pot culture experiments too, where tobacco grown by no manure and farmyard manure, with a poor yield, gave a high nicotine content, and those grown by superphosphate and nitrate of soda or superphosphate with nitrate of soda and muriate of potash, with a much better yield, gave a comparatively low nicotine content. However, on the whole, the results clearly indicate that the nicotine content in tobacco is generally proportional to the yield or in other words to the growth of tobacco. Again when we examine the column containing kilos of leaves per kilo nicotine in Table VI we find that superphosphate or nitrate when applied alone tends to decrease the nicotine content, but a combination of these two manures tends to increase the proportion of nicotine.

Adolf Mayer[1] while studying the conditions of growth favourable to the development of nicotine content of tobacco, showed that not only manures but increased temperature, direct sunlight and increased humidity each individually favours the formation of nicotine, while an increased water content of soil, which is generally attended with a low dry matter of crop, hinders its formation. In general, it may be concluded that any factor which promotes the growth of the plant is advantageous to the formation of nicotine, and any which hinders the growth is disadvantageous to the formation of nicotine.

III. The effect of "Topping" and "Spiking" on the Yield and Quality of Tobacco.

"Topping" is an operation which consists in breaking the top at the growing point, when tobacco plants are 2 ft. to 2 ft. 6 in. high and when the bunch of young flowers as well put out The object of this operation is to prevent plants wasting their energies in sprouts, shoots, suckling, flowers and seeds.

"Spiking" is an operation which consists in breaking the top at the growing point, inserting a little skewer at the fracture and pushing it a little way down when the tobacco plants are about 1 ft. to 1 ft. 6 in. high. The object of this operation is to *dwarf* the plant, to prevent it throwing out more shoots, and to produce broad and coarse leaves, about ten of which constitute the crop.

"Topping" as described above is practised in America and all other tobacco-growing countries except India where over a considerable tobacco-growing area

[1] *Landw. Versuchs Stat.* 38, p p. 453-467.

spiking is more commonly adopted. In the Madras Presidency, however, where a good deal of tobacco is used for cigar making, topping as practised in America is carried on. The mass of the tobacco grown in India is consumed in the country by the people themselves for chewing purpose. The object of the cultivator is to grow a heavy crop of coarse tobacco, attention is never paid towards producing a better quality of tobacco suitable for cigar or cigarette making. The reason for this is obvious; there is little or no demand for tobacco of better quality within the country, neither are there agencies for supplying raw materials of better quality in large quantities to Great Britain and other countries for their tobacco factories.

The growers of tobacco are relatively poor men with small capital, their ideas are primitive, they have greater faith in their old practice of spiking because they believe that it brings forth a greater yield of the crop and consequently will fetch more price. The object of the experiment detailed below is to throw light on these two operations by making a study of their comparative effect on the yield and quality of tobacco.

In 1916-17 a number of plants in each of the fourteen plots were simply topped, while others were spiked. Since spiking was carried on earlier than topping, for each spiked plant, chosen for this experiment, another one of the same size and in close proximity to it was selected for topping. All such pairs of spiked and topped plants for experimental purpose were marked with proper labels and consequently there was no difficulty in identifying them when the crop was cut.

The dry weight of leaves and stems of plants from each of the various plots and of each variety (Pusa Type 28 and Surujmukhi) obtained by the two operations are set forth in Table VII given below,

TABLE VII.

Plot	Variety	Spiked		Topped	
		Dry weight of leaves	Dry weight of stems	Dry weight of leaves	Dry wiegnt of stems
		grm.	grm.	grm.	grm.
A	Pusa Type 28	202·3	36·5	187·0	61·7
A_1	Pusa Type 28	195·1	38·3	199·9	42·3
A_1	Surujmukhi	179·5	56·7	147·1	44·4
D	Pusa Type 28	301·5	52·6	247·8	59·0
D_1	Pusa Type 28	149·5	21·4	177·2	29·0
D_1	Surujmukhi	188·6	55·4	168·3	74·3
E_1	Pusa Type 28	204·0	50·7	213·6	50·4
E_1	Surujmukhi	294·4	80·6	259·8	113·0
E_1	Surujmukhi	191·8	72·5	234·0	79·5
	TOTAL	1906·7	464·7	1834·7	553·6

An examination of the figures in the above statement will show that in 5 cases the spiked plants gave a higher yield in leaves and in 4 cases the topped ones gave a higher yield. Taking the results as a whole, we find that the effect of spiking has been to increase the yield of leaves to a very small extent (4 per cent.) over topping, and the effect of topping has been to increase the weight of stems by 20 per cent. over spiking.

In 1917-18, a plot 30 ft. by 24 ft. was manured with superphosphate and farmyard manure. The manured plot was divided into 4 quadrants each 12 ft. by 15 ft. and in each of these 4 plots, a variety known as Kawnia was transplanted. In two of the diagonally situated plots, all the plants were topped. The spiking was carried on when the plants were 1¼ ft. high as is the common practice in the country. Topping was carried on when the plants were 2 ft. high and young flowers were showing. The average number of leaves to each plant was 12 in case of spiked ones and 14 in case of topped ones.

The results obtained are set out below—

TABLE VIII.

Kawnia Spiked		Kawnia topped	
Dry weight of leaves	Dry weight of stems	Dry weight of leaves	Dry weight of stems
Kilos	Kilos	Kilos	Kilos
3·58	1·039	3·82	1·456
3·37	1·016	3·03	1·337
6·95	2·055	6·85	2·793

An examination of the figures in the above table will show that the yield of tobacco leaves by both the operations (spiking and topping) are almost identical and that the effect of topping has been to increase the yield of stems by about 36 per cent. over spiking. It thus confirms previous year's results.

So far as the quality of tobacco in respect of texture, colour, elasticity etc., is concerned, Mr. A. C. Acree, Director of the Indian Leaf Tobacco Development Company, Dalsing Sarai, reported the topped ones as decidedly superior to the spiked ones. His report runs as follows :—" In regard to the four samples of Kawnia tobacco my opinion is the tobaccos which have been topped are the best." In the first year three samples of tobacco which were topped and the corresponding three samples which were spiked were submitted to a chemical analysis for those constituents which are commonly recognized as affecting the quality of tobacco. In the following year 1917-18 all the four samples of spiked and topped tobaccos

were examined for the same constituents. The analytical figures obtained in 1917-18 confirmed the previous year's result which points to the conclusion that the relative effects of either topping or spiking on the ash, potash, chlorine and protein contents of tobacco are in no way appreciable, and that topped plants in majority of cases gives a higher nicotine content. These will be evident from an examination of Table IX given below :—

TABLE IX.

Samples	Spiked						Topped					
	Pure ash	Potash (K_2O)	Chlorine (Cl)	Amido nitrogen	Albd. nitrogen	Nicotine	Pure ash	Potash (K_2O)	Chlorine (Cl)	Amido nitrogen	Albd. nitrogen	Nicotine
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
Average samples of Pusa 28 and Surujmukhi from plot A_1 & D_1	19·87	2·35	0·19	0·277	1·301	3·54	19·74	2·69	0·19	0·248	1·437	4 08
Average samples of Pusa 28 from plots A & D	18·74	3·18	0·68	0·280	1·004	4·60	19·34	3 71	0·84	0·260	0·943	4·29
Average samples of Surujmukhi from Plots E_1 & F_1	19·62	2·82	0·68	0·292	1·195	3·61	19·04	2·30	0·53	0·254	1·290	3·97
Kawnia No. 1, 1917-18	17·50	1·82	0·42	0·210	1·080	4·64	16·02	1·80	0·56	0·210	1·090	5·09
Kawnia No. 2, 1917-18	15·89	1·93	0·16	0·270	1·100	4·46	16·35	1·81	0·17	0·280	0·970	4·92

A comparative test on the burning capacities of topped and spiked samples of Kawnia grown in the experimental plot were made by Toth's apparatus. The topped sample gave a higher combustion value (650) against the spiked one with a value of 500. When smoked the topped ones burnt better than the spiked ones.

The result of the comparative effect of topping and spiking obtained during two successive years' experiments therefore show that :—

(1) The yield of tobacco leaves by both the operations topping and spiking are almost identical.

(2) Topping has the effect of increasing the outturn of stalk and stem, which apart from its value as fuel, has a manurial value too. The stems are also used in snuff making.

(3) Topping has the effect of improving the quality of a tobacco and making it suitable for cigar and cigarette making, whereas spiking produces a tobacco of a coarse, inferior quality and not so suitable for cigar or cigarette making.

(4) There is hardly any difference between topped and spiked tobacco, so far as their ash, potash, chlorine, and protein contents are concerned.

(5) Topped plants in a majority of cases give a higher nicotine content.

(6) Topping produces tobacco of a better burning quality than spiking.

If topping has the effect of improving the quality of a tobacco to such an extent how is it that the Indian ryots and cultivators do not adopt this practice? The reasons are obivious. Firstly, there is little or no demand for such tobacco in this country. Only a few cigarette manufacturing companies now established in India, such as the Peninsular Tobacco Company, Monghyr, are the only concerns which appreciate and demand such a product. Apart from these there are very few agencies in India at present who would deal with such an improved product in the way of supplying other countries. The bulk of tobacco grown is consumed in the country by the people themselves for chewing purpose and topped tobaccos do not as a rule appeal to their tastes. Secondly, the cultivators are under a misapprehension that topped tobacco will always give a lesser yield of leaves by weight and so will fetch a lesser price. In fact, if topping is carried on properly and if on the average fourteen leaves are kept to each plant, topping gives as good a yield as spiking. Pitsch[1] from his experiments conducted at Wageningen, to ascertain the effect on the size and fineness of the leaves of topping to ten, twelve and fourteen leaves per plant, has shown that the total weight of dried leaves on 10 plants, topped to ten, twelve and fourteen leaves, were 422·5, 564·1 and 875·9 grm. respectively. Not only were the total leaves with fourteen leaves the largest but these plants also gave the largest yield of high grade tobacco. He further noticed that the leaves were as a rule larger and thicker when fourteen leaves remained than when twelve were left. In the present experiment 14 leaves were kept to each plant when topped and the size of

[1] *Deut Lander. Presse*-. 20 (1895), No 76.

the leaves of the resulting plants were in no way inferior to the leaves from spiked plants. Thirdly, the cultivators here have no idea that topped plants give a much higher outturn of stems which has got a good manurial value as the following analysis of two samples of stems indicate.

—	Air-dry tobacco stems, 1917	Air-dry tobacco stems, 1918
	Per cent.	Per cent.
Organic nitrogen	3·07	2·53
Phosphoric acid (P_2O_5)	0·98	0·54
Potash (K_2O)	4·65	4·43

In this connection, Davidson,[1] from his examination of 4 varieties of tobacco, has shown that about one-third of the fertilizing constituents are lost in tobacco stems and roots which should be returned to the soil. Lastly strong tobacco having a high nicotine content finds a good market in this country; the cultivators are under a misapprehension that topping has the effect of always reducing the nicotine content to a great extent; this is hardly the case, as the results of the present experiment indicated.

IV. Ground-curing and Rack-curing.

Ground-curing is the ordinary method of curing tobacco which is generally followed throughout India and is carried out in the following manner.

The plants are cut and allowed to lie on the ground for a couple of days after which they are carried to some grassy spot and laid out so as to be exposed to the sun during the day and to the dew at night, being turned daily. After eight or ten days of this treatment every third or fourth day, the plants are stacked together till they become heated, when they are again spread out to cool.

If at this time sufficient dew does not fall at night a little water is sprinkled over the leaves at evening-time, and this treatment proceeds for twenty days or more. The plants are then brought into cover and stacked; they are turned every third and fourth day, the top going to the bottom and bottom to the top and so on. At this stage, every care is taken to prevent the tobacco getting overheated. If the leaves show a tendency to dry, the heaps are covered with plaintain leaves, over which is placed a blanket or gunnies.

Ground-curing produces tobacco of a dark brown hue and generally of leaves of small elasticity. For cigarettes, this dark brown colour is undesirable and the more this develops, the lower is the value of the product. For Indian market, colour is of very little importance and no care is ever taken to produce tobacco of a light colour.

[1] *Virginia State Bull.* 14, 1892.

Since ground-curing does not produce tobacco of a suitable quality for cigarette manufacture and since flue curing in barn does not suit the local conditions prevailing in this country, the Peninsular Tobacco Company suggested the process known as "rackcuring" which consists of the following operations. Before the crop is harvested the stems are split with a knife, almost to the ground, then cut down and crop left lying on the field for about three hours. When the plants are a little wilted they are inverted and slung on bamboo sticks, so that they just touch one another side ways. The loaded sticks are then hung on bamboo racks provided with a thatched roof made of grass. The tip of the leaves are kept about a foot above the ground, and sufficient space for drying and for free circulation of air is maintained between the rows of loaded sticks as they are placed on the rack. The object of the roof is to protect the plants from dew and rain. When the midribs of the leaves are dry the plants are taken down and the leaves stripped off and bundled. The advantages of this method of curing are evident; there is lesser probability of the leaves being broken and bruised here than is the case with ground-curing where the crop is handled too often, the drying is also slower and the rapid oxidation process in presence of moisture, which changes the colour from yellow to brown, is avoided by protecting the plants from dew.

The object underlying the experiment now under review was to make a comparative study of the changes occurring during the process of curing by these two methods.

In March 1917, a number of plants from one large plot were rack-cured and the rest from the same plot were ground-cured by the ordinary country method. A sample of the rack-cured and one of the ground-cured tobaccos of one and the same variety and grown in the same field were obtained from the Indian Leaf Development Company, Dalsing Sarai. These four samples of tobacco (two ground-cured and two rack-cured) were analysed for their ash, potash, chlorine, amido nitrogen and nicotine contents. An examination of these samples (Table X) showed that excepting the nicotine the other constituents were hardly affected.

TABLE X.

Constituents	Tobacco from Dalsing Sarai		Tobacco from Pusa Pot Culture House	
	Rack-cured	Ground-cured	Rack-cured	Ground-cured
	Per cent.	Per cent.	Per cent.	Per cent.
Nicotine	2·25	2·65	2·79	3·59
Pure ash	19·37	16·95	17·66	19·70
Potash as K_2O	3·17	2·82	3·46	3·17
Chloride as Cl	0·75	1·90	0·29	0·36
Amido nitrogen	0·25	0·32	0·17	0·13

The results tabulated in Table X indicate that rack-curing has the effect of reducing the nicotine content appreciably. The reduction of nicotine (specially the volatile nicotine) in the tobacco by rack-curing may also account for the suitability of such tobacco for cigarette manufacture.

Garner [1] has shown that nicotine exists in two forms in tobacco, one of which is easily volatile and readily soluble in petroleum ether, while the other is volatile only at elevated temperatures and is almost insoluble in petroleum ether. He has further shown that the undesirable sharpness or pungency contained in the smoke of certain types of cigar filler tobacco is due almost entirely to the volatile easily soluble form of nicotine which acts, as if it were, in the free state. The pungent harsh quality of smoke is partially but not entirely removed by protracted resweating and aging of the tobacco, whereby easily volatile nicotine is largely expelled. It would, therefore, appear that during the process of curing on rack, owing to the free circulation of air round the plants and slow drying of the tobacco, a large proportion of the so-called volatile nicotine, which gives the undesirable sharpness or pungency to the smoke from certain types of tobacco, is expelled and the quality, improved thereby.

With a view to obtain confirmation of these results and ascertain how much of the sugar and starch of tobacco are consumed during the process of rack-curing and ground-curing, estimations were made on tobacco cured by both these processes during 1918. For this purpose, two samples of rack-cured and two samples of ground-cured tobaccos were prepared and examined. The results are set forth in Table XI and show that, as in the previous year, the ash, potash and amido nitrogen were practically unaffected by any of the two processes, but that the effect of rack-curing was to reduce appreciably the nicotine content.

TABLE XI.

Constituents	Tobacco plot B		Tobacco plot D	
	Rack-cured	Ground-cured	Rack-cured	Ground-cured
	Per cent.	Per cent.	Per cent.	Per cent.
Nicotine	4·28	4·54	4·84	5·85
Pure ash	17·68	17·22	17·74	17·17
Potash (K_2O)	3·11	2·97	2·27	2·40
Chlorine (Cl)	..	0·22	0·39	0·42
Amido nitrogen	0·296	0·232	0·206	0·248

[1] *U. S. Dept. of Agri. Bureau of Plant Industry, Bull.* 141, Pt. I.

In order to test the efficacy of rack-curing in removing a portion of the so-called volatile nicotine, samples of tobacco latterly cured by the ground and the rack processes were extracted with petroleum ether and ether successively (the petroleum ether dissolving the volatile nicotine and the ether the total nicotine), and volatile and Fixed nicotine determined in the extract. A brief summary of the results obtained is given in the following table. :—

TABLE XII.

Constituents	Sample 1		Sample 2	
	Ground-cured	Rack-cured	Ground-cured	Rack-cured
	Per cent.	Per cent.	Per cent.	Per cent.
Volatile nicotine	1·74	1·57	2·53	2·27
Fixed nicotine	3·11	3·06	0·91	0·98

A comparison of the results obtained clearly shows that ground-cured tobacco gives a higher content of volatile nicotine than rack-cured ones; that is to say, rack-curing is more effective than groundcuring in reducing the volatile nicotine.

Estimation of the sugar content of tobacco in fresh samples before curing and in the corresponding cured samples indicated that the proportion of reducing sugar to the total sugar increases in both the processes but the amount of total sugar consumed by both these processes of curing is quite irregular.

With regard to the starch, the rack-cured tobaccos showed a higher content than those cured on ground or in other words the destruction of starch was greater in case of ground-cured tobaccos than those cured on racks as is evident from the following table :—

TABLE XIII.

Description of samples	Fresh sample starch	Rack-cured starch	Ground-cured starch
	Per cent.	Per cent.	Per cent.
Sample B-P	4·84	3·73	2·23
Sample D_1-P	6·34	3·52	3·29

Studies on tobacco curing by these two processes have thus shown that—

(1) Rack-curing produces tobacco of a bright yellow colour quite suitable for cigarette manufacture, while ground-curing produces tobacco of dark brown hue.

(2) Rack-cured tobacco leaves possess greater elasticity than ground-cured leaves and hence suit better for cigarette making.

(3) Rack-curing has the effect of reducing the nicotine content and specially of the volatile nicotine, and it is this constituent which gives an undesirable sharpness or pungency to the smoke.

(4) Rack-curing produces tobacco with a higher starch content than those cured on ground.

Though rack-curing has so many advantages over the ground-curing process, the disadvantages attending it are in no way less. Rack-curing entails a good deal of expense and supervision as has been pointed by Howard and Howard[1] in the following words :—" A considerable amount of labour and expense are involved in the errection of the curing racks. The curing process is a long one and the crop is on the rack for at least six weeks, during which it is liable to damage by wind, rain and hail. Towards the end of the process, the danger of fire has to be guarded against. A good deal of supervision is required when the cured plants are taken off the racks and the leaves are stripped and baled."

The disadvantages attending the ground-curing method to produce a tobacco more suitable for cigarette manufacture are chiefly two : firstly, it produces tobacco of a dark brown hue, and, secondly, ground-cured tobacco leaves are harsh to the feel and possess less elasticity. As regards the latter, if damage to the leaves and stalks is avoided as far as possible by carefully handling the crop when spreading and stacking it and if the tobacco is not dried too fast, it will produce leaves possessing good elasticity.

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[1] *Pusa Agri. Res. Inst. Bull.* 50.

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Further Experiments on the Influence of Manures on the Yield and Morphine Content of the Latex from the Opium Poppy

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

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FOREWORD.

The writer was placed on special duty at the end of 1916 in order to investigate the reason for the low morphine content of Indian opium. The matter was of national importance, since in pre-war days the bulk of opium used for medicinal purposes was obtained from Turkey and when this latter country came into the war on the side of our enemies supplies of medical opium from that source ceased. Very shortly after the period of my special duty commenced, I was fortunate enough to discover the reason for the low morphine content of Indian opiums. The remedy was fortunately a simple one. Indian opium was shipped to Europe in sufficient quantities to supply all war-time needs. If necessary India is now in a position to supply opium of high morphine content. The work carried out under my direction has been published in previous memoirs of this series and elsewhere. Early in 1924, however, it was decided by Government to close down the research work on medicinal opium.

At that time a number of investigations were in process.

The memoirs now published describe such of these investigations as had reached a stage suitable for publication at the time the work was wound up.

H. E. ANNETT,

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INVESTIGATIONS ON INDIAN OPIUM, NO. 4. FURTHER EXPERIMENTS ON THE INFLUENCE OF MANURES ON THE YIELD AND MORPHINE CONTENT OF THE LATEX FROM THE OPIUM POPPY.

BY

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AND

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[Received for publication on 7th May, 1925.]

In a previous publication, one of us[1] has described the results of four years' experiments on the influence of manures on the yield and composition of the latex from the opium poppy. An account of manurial experiments on other drug producing plants carried out by other workers was there given.

In the season 1920-21 and 1921-22 we have carried out further experiments in continuation of our previous work. The experiments carried out in the first three years 1916-17, 1917-18, 1918-19 showed that potash manures had little effect on either yield of opium or its morphine content. Superphosphate[2] had apparently, little effect, but there were cases in which it appeared to give a larger yield of latex. Nitrate of soda and organic manures, however, gave large increases in yield of latex, and there were indications of a slight increase in the percentage of morphine in the latex. Accordingly in the season 1919-20 the experiments were limited to determining the effect of various amounts of nitrate of soda and of poppy cake and castor cake. Large increases of latex yield were obtained with the nitrate dressings, but poppy cake gave a larger yield and castor cake the largest yield of all. With increasing amounts of nitrate there was a small but significant increase in the percentage of morphine in the latex, and the highest percentage of morphine was obtain-

[1] *Mem. Dept of Agri. in India, Chem. Series,* Vol. VI, No. 2.

[2] For a reconsideration of these results as regards superphosphate see this paper, page 33.

ed in the case of the castor cake plots. The results obtained with nitrate of soda in increasing the outturn of opium were so definite that trials were carried out with cultivators in the Rae Bareli District. Mr. Bryan of the Opium Department organized and carried through this district work with the aid of Mr. Farnon. About 30 acres of land belonging to 51 cultivators were used for the experiment. The land receiving nitrate gave an average increase of 30 per cent. and 31·5 per cent. in outturn of opium and seed respectively. In only 6 out of the 51 cases were the non-nitrate plots superior to the nitrated ones.

1920-21 Experiment.

It was decided to carry out a more elaborate experiment on the effect of nitrate of soda, superphosphate and organic manures in the season 1920-21. A field was chosen roughly 1·39 acres in area and on it were laid out 56 plots, each 30′×25′, equal to 1-60 acre in area. A margin 3′ wide was left all round the plots and between each line of plots. The field had been unmanured for some years past but had been regularly cropped. Seed of a pure race of the same kind used in our previous manurial experiments was used.

Manuring.

The following diagram and table show the arrangement of the plots. As will be seen each plot was quadruplicated :—

1	8	15	22	29	36	43	50
2	9	16	23	30	37	44	51
3	10	17	24	31	38	45	52
4	11	18	25	32	39	46	53
5	12	19	26	33	40	47	54
6	13	20	27	34	41	48	55
7	14	21	28	35	42	49	56

Plots No.	Treatment per acre			
1, 17, 33, 49	No manure			
14, 26, 38, 50	$NaNO_3$	160 lb.		
8, 24, 40, 56	$NaNO_3$	320 ,,		
7, 19, 31, 43	$NaNO_3$	480 ,,		
3, 15, 35, 47	$NaNO_3$	640 ,,		
2, 18, 34, 51	Super	240 ,,		
6, 23, 39, 55	Super	240 ,,	$NaNO_3$	160 lb.
4, 20, 32, 44	Super	240 ,,	$NaNO_3$	320 ,,
9, 25, 41, 53	Super	240 ,,	$NaNO_3$	480 ,,
13, 16, 37, 48	Super	240 ,,	$NaNO_3$	640 ,,
5, 21, 29, 45	Cattle dung	20,000 lb.		
12, 28, 36, 52	Castor cake	1,600 ,,		
11, 27, 30, 46	Castor cake Super	1,600 ,, 240 ,,		
10, 22, 42 54	Poppy cake	1,600 ,,		

The whole field having been well prepared was set out in plots on 5th November, 1920, and the castor cake, poppy cake, cattle dung and superphosphate were all applied on that day. The field was irrigated on the 6th, 7th and 8th November, and was sown on 11—15th November. It was unfortunate that the conditions of different parts of the field were such that it could not all be sown on the same day. The plots receiving nitrate had it in two equal dressings, the first being applied on 19th January, 1921. A timely fall of rain occurred the next day. The second dressing of nitrate was given on 21st February, 1921, and was followed by an irrigation.

Harvesting of produce.

Lancing for opium commenced on 20th March, 1921. It was not practically possible with the staff at our command to lance all plots on the same day. The lancing was, therefore, carried out as in the following programme.

Nos. of plots lanced	Dates of lancing		
	1st	2nd	3rd
43—56	20th March 1921	25th March 1921	29th March 1921.
29—42	21st March 1921	26th March 1921	
15—28	22nd March 1921	27th March 1921	30th March 1921.
1—14	23rd March 1921	28th March 1921	

In considering the results one must therefore take into account the possibility of the effect on the yield due to the different weather conditions on the different days on which lancing took place. As far as we are able to judge there was no marked difference in weather conditions during the lancing period.

After lancing had been completed the plants were allowed to ripen. They were then cut and dried in the sun and their total weight determined. The seed was then separated and weighed.

The morphine content of the opium of the first lancing only was determined. The total dry weight of the opium of each lancing was estimated by taking a portion of each sample for drying in the water oven.

In the following table we have summarized our results.

Effect of manures on outturn and morphine content of opium, Cawnpore, 1920-21.

Plot No.	Manurial treatment per acre	Total sun-dried plant oz.	WEIGHT OF PRODUCE PER PLOT					Per cent. morphine on dry matter of 1st lancings
			Seed oz.	OPIUM (DRY MATTER) GRM.				
				Lancings				
				1st	2nd	3rd	Total	
1	2	3	4	5	6	7	8	9
1 . .	*nil*	206	62	48	8·2	2·2	58·4	11·5
17 . .		264	70	58	5·4	1·6	65·0	11·4
33 . .		248	62	53·4	6·0	2·1	61·5	9·4
49 . .		382	83	56·4	18·4	4·5	79·3	12·0
Average .	....	*300*	*69 2*	*53·9*	..	..	*66·0*	*11·1*
14 . .	$NaNO_3$ 160 lb.	248	62	40·9	4·2	0·5	45·6	11·5
26 . .		296	72	57·8	5·7	0·7	64 2	9·7
38 . .		432	116	81·9	9·8	1·4	93·1	11·6
50 . .		616	136	70·0	14 2	0 8	94 0	11·2
Average .	....	*398*	*96 4*	*64·9*	..	..	*74·2*	*11·0*
8 . .	$NaNO_3$ 320 lb.	272	62	54·1	5 6	0·9	60 6	10·8
24 . .		264	68	63 6	7·7	0 5	71·8	9·5
40 . .		320	91	73·6	9·3	1 0	83·9	9·5
56 . .		332	84	55·8	11·5	0 5	67·8	11·9
Average .	....	*297*	*76·2*	*61·8*	..	..	*71·0*	*10·4*
7 . .	$NaNO_3$ 480 lb.	360	82	59 8	8 9	2 4	71·1	10 9
19 . .		220	61	48·4	3·7	0 7	52 8	11·4
31 . .		262	72	63·3	7·0	0·8	71·1	10·3
43 . .		648	167	74·3	5·8	0·3	80·4	13·0
Average .	....	*372*	*95·6*	*61·4*	..	..	*68·8*	*11·4*

Effect of manures on outturn and morphine content of opium, Cawnpore, 1920-21 —contd.

Plot No.	Manurial treatment per acre	Total sun-dried plant oz.	WEIGHT OF PRODUCE PER PLOT						Per cent. morphine on dry matter of 1st lancings
			Seed oz.	OPIUM (DRY MATTER) GRM.					
				Lancings					
				1st	2nd	3rd	Total		
1	2	3	4	5	6	7	8		9
3 . .	NaNO₂ 640 lb.	400	98	61·7	10 0	1·0	72·7		11·9
15 . .		244	72	51·4	5·0	0·2	56·6		10 9
35 . .		258	70	54·8	6·4	0·6	61·8		10·1
47 . .		404	98	85·6	16·[illegible]	1·6	103·5		10·0
Average .	....	*326*	*84*	*63·4*	..	..	*73·6*		*10·7*
2 . .	Super, 240 lb.	496	100	57·8	13·2	2·6	73·6		13·0
18 . .		432	103	70 0	7 2	1·0	78·2		12·0
34 . .		448	112	80·7	6·4	1·5	88·6		11 9
51 . .		424	114	50 6	10·6	1·5	62·7		12·5
Average .	....	*450*	*107·2*	*64·8*	..	..	*75 8*		*12 3*
6 . .	Super, 240 lb. NaNO₂ 160 lb.	376	84	85 6	12 5	3 1	101·2		12·8
23 . .		576	145	93·2	8 3	0 4	101·9		11·5
39 . .		532	128	76 3	9 3	0 8	86·4		10 7
55 . .		428	100	59 9	6 6	1·5	68·0		11·6
Average .	....	*478*	*114·2*	*78·7*	..	..	*89 4*		*11 6*
4 . .	Super, 240 lb. NaNO₂ 320 lb.	656	139	80·7	8 9	1·3	90 9		14 3
20 . .		580	148	78·8	6·8	0·7	86·3		12·6
32 . .		542	132	94 6	10 3	1·0	105 9		11·3
44 . .		702	170	79 8	9·1	0 8	89·7		12 7
Average .	....	*620*	*147·2*	*88·5*	..	..	*93·2*		*12 7*
9 . .	Super, 240 lb. NaNO₂ 480 lb.	640	146	89·0	16·3	2·1	107·4		12·5
25 . .		480	106	80·9	7·7	0·4	89·0		10 5
41 . .		388	91	63·1	4·2	0·5	67·8		10·9
53 . .		624	144	97·1	13·7	0·8	111·6		11·8
Average .	....	*532*	*121·8*	*83·0*	..	..	*93·9*		*11·4*

Effect of manures on outturn and morphine content of opium, Cawnpore, 1920-21 —concld.

Plot No	Manurial treatment per acre	Total sun-dried plant oz.	WEIGHT OF PRODUCE PER PLOT						Per cent morphine on dry matter of 1st lancings
			Seed oz	OPIUM (DRY MATTER) GRM.					
				Lancings					
				1st	2nd	3rd	TOTAL		
1	2	3	4	5	6	7	8		9
13 .	Super, 240 lb NaNO$_3$, 640 lb.	480	114	61.4	4.7	0.5	66.6		12.0
16 . .		552	136	103.0	6.2	0.4	109.6		11.9
37 . .		588	152	87.4	6.0	0.4	93.8		12.5
48 .		428	104	64.4	9.3	1.0	74.7		12.7
Average	...	*462*	*126.4*	*79.0*	..	.	*86.2*		*12.3*
5 . .	Cattle dung, 20,000 lb.	404	94	41.8	5.0	1.2	48.0		13.9
21 . .		530	128	45.0	6.4	0.7	52.1		13.5
29 . .		688	160	64.5	5.1	1.0	70.6		13.7
45 . .		572	121	57.3	6.7	0.4	64.4		14.0
Average	...	*534*	*125.8*	*52.1*	..	..	*58.8*		*13.8*
12 .	Castor cake, 1,600 lb	528	128	59.8	3.4	0.6	63.8		12.9
28 . .		524	132	61.5	3.8	0.1	65.4		12.7
36 .		580	150	80.4	6.1	0.9	87.4		12.9
52 .		500	122	61.4	10.2	0.6	72.2		12.9
Average .	...	*533*	*133*	*65.8*	.	..	*72.2*		*12.8*
11 . .	Castor cake, 1,600 lb Super, 240 lb.	600	170	66.9	7.9	1.7	76.5		12.9
27 . .		688	170	58.8	3.9	0.2	62.9		13.7
30 . .		640	156	72.8	5.6	0.4	78.8		13.3
46 . .		704	152	78.9	12.7	1.2	92.8		14.2
Average .	..	*658*	*162*	*69.3*	.	.	*77.8*		*13.5*
10 . .	Poppy cake, 1,600 lb.	564	128	62.5	17.6	4.5	84.6		13.6
22 .		640	152	84.3	7.3	0.4	92.0		11.4
42 .		272	66	31.8	7.2	1.5	40.5		12.3
54 . .		454	104	55.5	10.0	1.4	66.9		11.3
Average .	....	*482.4*	*112.4*	*58.5*	..	..	*71.0*		*12.1*

An examination of the above figures shows that nitrate of soda applied alone has usually given a distinct increase in the weight of the crop and of the seed. It has usually given a distinct increase in outturn of opium from the first lancing over the unmanured plots, but when the total yield at all lancings is considered the increase is much less noticeable. When applied alone the nitrate of soda appears to have had no effect in the morphine content of the opium.

The effect of superphosphate alone appears to have had a larger effect than nitrate of soda in increasing the outturn of total produce and of seed, but it has had only a small effect on the yield of opium. It seems, however, to have caused a small increase in the morphine content of the opium.

Superphosphate applied in conjunction with nitrate of soda has brought about very large increases in yield of total produce, in seed, and in the yield of opium. The morphine content of the opium appears also to show a distinct increase over that from the unmanured plots.

Cattle manure has given large increases in total produce and in seed outturn, but has not increased the yield of opium. It seems, however, to considerably increase the morphine content of the opium. It must be borne in mind that the cattle dung was put on very late only 6—10 days before sowing.

Castor cake alone has given a considerable increase in outturn of total produce and of seed and a small increase on opium yield. It has, moreover, produced a small increase in morphine content of the opium.

Castor cake combined with superphosphate has given better results all round than castor cake alone and has produced a decided increase in morphine content of the opium.

Poppy cake has given distinct increases in outturn of total produce and of seed but no appreciable increase in outturn of opium or amount of morphine in the opium.

Since superphosphate appears to have had a distinct effect in increasing the morphine content of the opium we have re-examined our results with superphosphate obtained on the manurial experiments carried out in 1916-17 and 1917-18. In those years the plots were only duplicated and not quadruplicated as in our more recent experiments. It would seem to us that our earlier results might be taken to indicate that superphosphate did have some effect in increasing the morphine content of the opium. The reader is particularly referred to our Memoir[1] quoted below. At the time that work was published it did not appear to us legitimate to conclude that the effect observed was significant.

1921-22 Experiments.

The experiments carried out in this season were on different lines. Superphosphate was not used but the experiment was designed to test the effect of nitrate of

[1] *Mem. Dept. of Agri. in India, Chem. Series*, Vol. VI, No. 2, pp. 101, 102, 106.

soda alone and in combination with castor cake. Experiments with cattle dung and with nitrate of potash were also added to the series.

A pure race of seed was used, the same which has been used in all our manurial trials. Each plot was quadruplicated. The field used had been unmanured for many years previously but had been continuously cropped. It measured approximately 2 acres in area. The field was divided into 36 plots each 60′×15′ or nearly 1-48 acre each. All around each plot a marginal area 3 feet wide was left. In one part of the field a trial pit had been dug by the Public Works Department. A whole strip 14 feet wide which included this pit and running the length of the field was left out of the experiment. It was, however, sown with poppy having been manured with poppy cake at the rate of 7 maunds per acre.

Manuring.

The diagram and tables show the arrangement of the plots which, as stated above, were quadruplicated.

1	7	13	19	25	31
2	8	14	20	26	32
3	9	15	21	27	33
4	10	16	22	28	34
5	11	17	23	29	35
	Not under experiment.				
6	12	18	24	30	36

Plots No.	Treatment per acre
8, 11, 26, 29	No manure.
7, 10, 25, 28	Sodium nitrate, 160 lb.
9, 12, 27, 30	Do. 320 lb.
2, 5, 20, 23	Castor cake, 560 lb.
14, 17, 32, 35	Do. 1,120 lb.
1, 4, 19, 22	Castor cake, 280 lb. Nitrate of soda, 80 lb.
15, 18, 33, 36	Castor cake, 560 lb. Nitrate of soda, 160 lb.
13, 16, 31, 34	Cattle dung, 20,000 lb.
3, 6, 21, 24	Potassium nitrate, 160 lb.

The land having been prepared and set out in plots, the castor cake and cattle manure were applied on 19th October, 1921, and ploughed in. The seed was sown broadcast at 6 lb. per acre on 22nd and 23rd November, 1921. The nitrate of soda and potash dressings were put on in two equal dressings, the first on 24th January, 1922, and the second on 25th February, 1922.

Harvesting of produce.

The first lancing of all the plots took place on 23rd March, 1922, the second lancing on the 26th, the third on the 29th and the 4th and final lancing on 1st April, 1922. Unfortunately, however, through an oversight complete records of yields of the first lancings only were obtained. Analyses were, however, made of the morphine content of the opium of the first lancing from each plot and the figures are set out in the accompanying table.

Plot No.	Manurial treatment per acre	Per cent. morphine in dry matter of opium of 1st lancings
8	nil	11·6
11		12·6
26		10·9
29		9·9
Average	....	*11·2*
7	$NaNO_3$ 160 lb.	12·8
10		12·3
25		12·1
28		10·4
Average	....	*11·9*
9	$NaNO_3$ 320 lb.	12·5
12		12·7
27		10·4
30		1·7
Average	....	*11·8*

Plot No.	Manurial treatment per acre	Per cent. morphine in dry matter of opium of 1st lancings
2	Castor cake, 560 lb.	13·7
5		12·7
20		13·1
23		10·4
Average	....	*12·5*
14	Castor cake, 1,120 lb.	13·2
17		13·1
32		13·2
35		13·2
Average	....	*13·2*
1	Castor cake, 280 lb. $NaNO_3$ 80 lb.	12·8
4		12·7
19		11·6
22		9·7
Average	....	*11·7*
15	Castor cake, 560 lb $NaNO_3$ 160 lb	13·3
18		14·3
33		12·2
36		14·0
Average	....	*13·4*
13	Cattle dung, 20,000 lb.	12·8
16		13·7
31		13·2
34		12·2
Average	....	*13·0*

Plot No.	Manurial treatment per acre	Per cent morphine in dry matter of opium of 1st lancings
3	KNO_3 160 lb.	1[illegible]·1
6		13·6
21		9·
24		11·4
Average	....	*11·6*

Nitrate of soda alone seems to have no marked effect on the morphine content of the opium.

Castor cake, however, appears to have distinctly raised the morphine content of the opium except in the case of the plots which received only 280 lb. of castor cake and 80 lb. of $NaNO_3$ per acre. Cattle dung seems also to have considerably increased the morphine content of the opium. Nitrate of potash appears to have had no more effect than nitrate of soda on the morphine content of the opium.

In general, therefore, it appears that the organic manures, castor cake and cattle manure, have had a distinct effect in increasing the morphine content of the opium. This effect does not appear to be due to either the nitrogen or potash they contain, and it is possible it is due to phosphate, since superphosphate in the previous season's experiments produced a distinct increase in the morphine content of the opium.

Conclusions.

Organic manures such as cakes and cattle manure in addition to giving an increased yield of opium appear to produce an increase in its morphine content. The increased morphine content does not seem to be brought about by the nitrogen or potash supplied in the organic manure.

It is possible, however, that the effect is due to the phosphoric acid supplied in the organic manure, since superphosphate in our experiments of 1920-21 has brought about a distinct increase in morphine content of the opium. A reconsideration of our results obtained in the seasons 1916-17 and 1917-18 would appear to show that in those experiments also there were indications that superphosphate caused an increase in the morphine content of the opium.

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Memoirs of the Department of Agriculture in India

Investigations on Indian Opium, No. 5

Experiments on Oil-Content of the Seed of the Opium Poppy

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INVESTIGATIONS ON INDIAN OPIUM, NO. 5. EXPERIMENTS ON OIL CONTENT OF THE SEED OF THE OPIUM POPPY.

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During the course of our work on the factors influencing the alkaloidal content of Indian opium we have carried out a few experiments on the oil-content of the seed produced by the same pure race grown under different manurial conditions and in different localities. We have also determined the oil-content of the seed produced by a number of different pure races in four successive seasons. The opium poppy plant usually produces a number of capsules, the terminal one being the oldest. We have determined the oil-content of the seed produced by the terminal capsules, *i.e.*, the oldest, and by the younger or lateral capsules. A few figures were also obtained for the oil-content of seeds produced both by capsules which had been lanced and unlanced for opium on the same plot.

Method of analysis used. About 20 grm. of seed were crushed in a coffee mill and 4 grm. were taken for extraction with ether in the Soxhlet Apparatus in the ordinary way. After 4 hours' extraction the extracted residue was removed from the thimble, dried in the air before a fan, and having been ground up in a mortar was re-extracted in the same thimble and apparatus for 2 hours more. Since poppy oil is a semi-drying oil, care was taken to carry out all the analyses in exactly the same manner particularly as regards length of time during which the extracted oil was finally dried before weighment.

1-2 grm. of the original crushed seed were dried in the water oven for 5-6 hours in order to determine the moisture content.

In the first table are given the figures obtained for the oil-content of the seed of a number of pure races grown at Cawnpore in three successive seasons and of three of these races grown at Budaun 200 miles from Cawnpore in the fourth season. The pure races were originally isolated by Dr. H. Martin Leake.

TABLE I.

Effect of season on oil-content.

No. of Pure Race	Oil per cent. on dry matter of seed			
	1919-20 Cawnpore	1920-21 Cawnpore	1921-22 Cawnpore	1922-23 (Budaun)
50	50·8	49·1	49·3	50·3
251	51·7	52·0	52·3	..
287	47·9	48·9	47·9	..
343	50·0	47·8	48·7	..
347	46·5	49·0	46·6	..
1596	52·0	51·3	50·0	52·3
1641	49·1	49·7	46·3	48·1
1644	50·4	49·8	48·1	..
1645	50·9	49·7	46·6	..

The variations among the figures for oil-content given in the table are so small that it is difficult to draw any definite conclusions from them. The pure races do not differ much among themselves though Nos. 287 and 347 seem poorer than the others. There is little seasonal variation and the climate of Budaun does not seem to have affected the oil-content of the seed.

In the season 1919-20 a series of manurial experiments was carried out in which different amounts of nitrate of soda were applied to a series of plots. Two plots receiving poppy cake and castor cake respectively were also included in this series.

In the season 1921-22 the manurial scheme was rather different. These manurial experiments were carried out in connection with our work on the alkaloid content of the latex. The seed, however, was available for the purpose of oil determination.

TABLE II.

The effect of increasing amounts of nitrate of soda on the oil-content of poppy seed, 1919-20.

No. of Plot	Manurial treatment per acre	Oil per cent. in dry matter of seed produced by	
		Unlanced heads	Lanced heads
11	*nil*	48·6	48·9
1	$NaNO_3$, 80 lb.	48·8	..
16	„ 80 lb.	48·1	49·2
15	„ 160 lb.	48·5	..
12	„ 320 lb.	49·2	49·3
10	„ 480 lb.	48·2	48·2
13	„ 640 lb.	48·1	48·8
9	Poppy cake, 1,600 lb.	49·0	48·1
14	Castor cake, 1,600 lb.	49·0	..

TABLE III.

The effect of nitrates and organic manures on the oil-content of poppy seed, 1921-22.

No. of plot	Manurial treatment per acre	Oil per cent. on dry matter of seed
8	*nil*	49·6
11	*nil*	50·3
7	$NaNO_3$ 160 lb.	49·7
10	„ „	49·4
9	„ 320 lb.	49·2
12	„ „	50·0
3	KNO_3 160 lb.	51·0
6	„ „	50·0
2	Castor cake, 560 lb.	50·2
5	„ „	50·1
1	Castor cake, 280 lb. $NaNO_3$ 80 lb.	50·0
4	„ „	49·8
15	Castor cake, 560 lb. $NaNO_3$ 160 lb.	50·7
P_1	Poppy cake, 560 lb.	49·5
P_2	„ „	50·9
14	Castor cake, 1,120 lb	50·3
13	Cattle dung, 20,000 lb.	50·8

The remarkable feature about Tables II and III is the small variation in oil-content throughout. We must conclude that the manures used have had no appreciable effect on the oil-content of the seed produced.

In Table II are given figures for oil-content of seed produced from capsules which have been unlanced as well as from those which have been lanced. The lancing process evidently does not interfere with the development of the seed as judged by its oil-content.

In Table IV are set out a few results showing the oil-content of seeds produced by the terminal, *i.e.*, the oldest capsules compared with that of seeds produced by

lateral capsules. We were led to investigate this point because we have shown that the lateral capsules produce opium much poorer in morphine content than do the terminal capsules.[1] The seed used was of a pure race K_{55} some of which had been grown for two seasons at Rae Bareli, 80 miles from Cawnpore.

TABLE IV.

The oil-content of seed produced by terminal capsules as compared with that produced by the lateral or younger capsules.

Season	Seed used	OIL PER CENT. ON DRY MATTER OF SEED		
		Terminal capsules	Ist lateral capsules	2nd lateral capsules
1920-21. Cawnpore	K_{55} Rae Bareli seed . .	49·2	48·7	49·2
Do. . .	K_{55} Cawnpore seed . . .	50·8	49·2	48·9
1919-20. Cawnpore	K_{55} Plot 34, Sub-plot 1 . .	48·8	49·0	48·9
Do. . .	K_{55} Plot 34, Sub-plot 11 . .	..	49·0	48·9

The first lateral capsules are several days younger than the terminal capsules, and the second lateral capsules are several days younger still. There appears, however, no difference in oil-content between the seed of the lateral and of the terminal capsules.

Finally, we append a table showing the oil-content of the seed of a pure race K_{55} which we have grown in bulk for several seasons past at Cawnpore. Some of this seed was continuously grown at Cawnpore, whereas some from the same original stock had been grown at Rae Bareli and Jeolikhote and then brought back to Cawnpore. Rae Bareli is a plains station 80 miles from Cawnpore but Jeolikhote is at an altitude of 4,000 feet in the Himalayas.

TABLE V.

The oil-content of the seed of the same pure race grown at Cawnpore in successive seasons.

Seed	OIL PER CENT. ON DRY MATTER OF SEED			
	1919-20	1920-21	1921-22	1922-23
K_{55} Cawnpore seed . . .	50·2	50·8	48·9	..
K_{55} Rae Bareli seed . .	50·2	49·2	48·6	47·9
K_{55} Acclimatized at Jeolikhote, 1 year	..	49·1	..	..
K_{55} Acclimatized at Jeolikhote, 4 years.	..	49·2	..	..

[1] *Mem. Dept. of Agri. in India, Chem. Series*, Vol. VI, No. 2, p. 62.

CONCLUSIONS.

The oil-content of the seed of the opium poppy as grown in the United Provinces seems to be remarkably constant. The difference in the oil-content of the seed of 9 pure races tested seems to be so small as to be barely significant. There is, moreover, no marked effect due to season, climate or manures tested. The terminal and lateral capsules appear to produce seed of the same oil-content. The process of lancing the capsule for opium has no apparent effect on the oil-content of the seed.

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Investigations on Indian Opium, No. 6

Studies on the Ash Constituents of Indian Opium

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INVESTIGATIONS ON INDIAN OPIUM, NO. 6.
STUDIES ON THE ASH CONSTITUENTS OF INDIAN OPIUM.

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In previous memoirs in this series the authors have described the results of studies on the effect of various factors on alkaloid and meconic acid content of the latex of the opium poppy. By far the most striking observation made was that the morphine content of the latex calculated on the dry matter showed a rapid fall in each successive lancing of the same capsule. We have also found in experiments only a few of the results of which we have so far published that the codeine content of the latex does not show this diminution in each successive lancing. Narcotine falls off to some extent but not in such a marked way as does morphine. The only other alkaloid present in any quantity is papaverine. but this does not appear to decrease or increase in amount in any regular fashion in successive lancings. Meconic acid we have shown to be present in amount almost exactly equivalent to that required to form meconates with the total alkaloids present.[1] The following table gives a typical set of analyses for the morphine, codeine, narcotine and papaverine content of the latex of a series of successive lancings from the same capsules. The opium was produced from poppies grown from a pure race of seed No. K 50 at Budaun, U. P., in the season 1922-23.

No. of lancings	Percentage on dry matter of latex				
	Morphine	Codeine	Narcotine	Papaverine	Total
1st . . .	17·5	2·74	7·31	0·28	27·83
2nd . . .	14·4	3·08	5·56	0·57	23·61
3rd . . .	9·4	2·75	4·93	0·73	17·81
4th . . .	7·5	2·52	4·43	0·53	14·98
5th . . .	5·8	2·31	4·48	0·56	13·15

It will be seen that the total alkaloid content of the latex falls off rapidly in each successive lancing and this fall is mainly due to the rapidly decreasing amounts of morphine in each successive lancing.

We felt that it would be of great interest to study the amount of other substances in each successive lancing, and we soon found that the ash constituents gave results of interest. Before describing our results it will perhaps be advisable to refer briefly to the methods of analyses adopted by us for ash constituents, since ash analysis is by no means easy and in considering results it is of importance to know what analytical methods were used.

Preparation of ash.

1. A two gramme portion of dry opium was ignited in an asbestos bath over a Teclu burner in order to obtain a quantitative figure for the ash content of the sample.

2. Twenty-five grammes of opium were charred over a low flame and then ignited till hard in an asbestos bath over a Teclu burner. It was ground to a powder while warm in a mortar and then replaced in the platinum crucible in the asbestos bath over the Teclu burner. By this means the ignition can be carried out at a dull redness. A small loss takes place in grinding, but the quantitative figure is obtained under 1.

3. In our preliminary work a certain number of ash determinations were made by moistening the opium with H_2SO_4 previous to incineration. The figures so obtained are referred to in the table as sulphated ash.

Analysis. The method used was that described in Methods of the Association of Official Agricultural Chemists, U. S. A., 1920, p. 15, with minor modifications.

Soluble sulphates were estimated by extracting the dry opium with hot water and precipitation with barium chloride in the presence of hydrochloric acid in the usual manner.

Chlorine. This was determined by the volumetric method given on p. 19 of the Methods of Official Agricultural Chemists, U. S. A., 1920.

The ash obtained was in practically all cases pure white. For the sake of convenience we have set out in the first table figures showing the percentage of ash in the opium of several sets of samples of successive lancings from the same heads. In some cases the figures given are for ash prepared by the sulphuric acid method. It is unfortunate that only two of the figures are expressed as percentages of dry matter in the opium. The air dry opium used by us always contained about 94 per cent. dry matter and the figures may be considered as reliable relative to one another. The figures in the table are for ash content of air dried opium except where otherwise stated.

TABLE I.

The ash content of opium of successive lancings from the same capsules.

Sample	Percentage of ash in opium of each successive lancing						Remarks
	1st	2nd	3rd	4th	5th	6th	
Plot 44, sub-plot 1 (sulphated ash) . .	2·31	3·41	4·69	5·95	6·30	7·22	
Plot 44, sub-plot 2	2·08	2·47	3·43	3·90	3·65	..	
Do. (sulphated ash) . . .	2·57	3·27	4·10	5·16	5·41	5·24	On dry matter.
Plot 44, sub-plot 3 (sulphated ash) . .	2·43	3·31	4·55	5·63	6·78	6·05	
Plot 44, sub-plot 4 (sulphated ash) . .	2·30	2·96	..	..	..	..	
No 144-149 (1920-21)	3·19	3·88	5·29	..	..	..	
No. 371-373 (1920-21)	2·48	3·75	5·07	..	..	..	
No. 216-233 (1918-19)	1·78	2·65	3·03	..	..	..	

The table shows that there is a rapid rise in ash constituents of the latex at each successive lancing up to the fourth. After that the rise is not usually so marked.

In the next table is set out a detailed analysis of two sets of three successive lancings of the opium from the same capsules. In all these cases the ash was prepared by simple ignition without the addition of H_2SO_4

TABLE II.

The composition of the ash of opium.

Sample	No of lancing	Ash on air-dried opium per cent	Percentage on dry ash									
			Sand and silica	P_2O_5	SO_3	CaO	MgO	K_2O	Na_2O	CO_2	Fe_2O_3 Al_2O_3	Mn_3O_4
Plot 19 (1918-19)	1st	1·78	20·13	17·10	11·67	10·97	1·16	33·79	1·05	1·18	5·17	0·00
Do. .	2nd .	2·65	10·79	14·85	16·90	10·35	1·03	44·39	0·80	1·32	..	0·00
Do. .	3rd .	3·03	13·47	12·51	18·28	9·52	1·09	38·14	0·85	0·64	..	0·00
Plot 371 (1920-21)	1st .	2·48	11·57	10·58	24·20	4·71	.	25·68	..	..	..	..
Do. .	2nd .	3·75	8·14	8·69	17·32	4·00	..	27·67	..	..	..	..
Do. .	3rd .	5·07	16·21	8·48	18·79	3·90	..	39·87	..	..	..	..

Neither in the ash nor in the original opium have we been able to find more than a faint trace of chlorine.

The above figures do not indicate any marked differences in the composition of the ash of each successive lancing. There is, however, no doubt of the increase in the total ash constituents in each of the three successive lancings.

It is well known that sulphates are commonly present in opium. The foregoing table, however, gives an inaccurate idea of the amount present since much of the sulphate disappears during ignition. The following table gives figures for the sulphate content of the opium itself. These figures were obtained by extraction of the opium with water and precipitation with barium chloride in the presence of hydrochloric acid in the usual way.

TABLE III.

The sulphate content of opium.

Sample No.	Description of sample	Percentage of SO_3 on dry opium
	1917-18—	
170	1st lancing	2·00
171	2nd „	2·39
172	3rd „	2·71
	1918-19—	
320	1st „	1·73
322	2nd „	2·13
324	3rd „	2·86
	1919-20—	
301	1st „	1·98
302	2nd „	2·46
303	3rd „	2·79
	1920-21—	
386	1st „	2·18
387	2nd „	2·73
388	3rd „	3·31

Unfortunately of the above samples the total ash content was only determined in the case of sample 386 and this contained 2·20 per cent. ash on dry opium. The amount of SO_3 found in the above table for this sample, *viz.*, 2·18 per cent. would amount to 99 per cent. of the ash. Table II, however, shows that the ash usually contains from 12 to 24 per cent. of SO_3 and hence during ignition a very large loss of SO_3 takes place.

Table III shows that a regular rise of SO_3 content takes place in each successive lancing.

We have carried out a few analysis of successive lancings of opium for phosphate content without going through the ordinary procedure of ashing the opium. We treated the sample of opium with sulphuric acid as in the Kjeldahl process, aiding the destruction of organic matter by occasional cautious additions of HNO_3. The liquid was finally diluted and boiled down till all HNO_3 was expelled. After dilution the excess of H_2SO_4 was removed by addition of barium chloride and the still acid liquid diluted to a known volume. An aliquot portion was taken for P_2O_5 estimation and silica removed in the ordinary manner by evaporation with hydrochloric acid twice, the residue being heated to about 120° C. to render silica insoluble. The residue was extracted with dilute nitric acid and after filtration ammonium nitrate and ammonium molybdate added to precipitate the phosphate. The phosphate was then estimated by Kilgore's titration process as in the usual manner.

Table IV gives the P_2O_5 content of the opium of three separate series of successive lancings determined as in the above manner.

TABLE IV.

P_2O_5 content of opium.

Sample	P_2O_5 in air-dried opium (about 94 per cent. dry matter) in each successive lancing					
	1st	2nd	3rd	4th	5th	6th
Plot 19 (1918-19) . .	0·350	0·397	0·432	..	..	..
Plot 44, sub-plot 2 . .	0·308	0·364	0·432	0·469	0·531	0·544
Plot 44, sub-plot 3 . .	0·300	0·363	0·393	0·465	0·505	0·502

There is thus a steady rise in P_2O_5 content in the opium of each successive lancing up to the 5th. Beyond that there appears to be no further rise.

In the case of plot 19 the P_2O_5 content of the ash of the same samples had already been determined (Table II). The ash was there found to contain 17·10, 14·85 and 12·51 per cent. P_2O_5 in the case of the 1st, 2nd and 3rd lancings respectively. The

ash content of these samples (Table II) was 1·78, 2·65 and 3·03 per cent. respectively. The figures given for the P_2O_5 content of these samples in the above Table IV, *viz.*, 0·350, 0·397 and 0·432 when calculated as percentages of the ash are 19·66, 14·98 and 14·26 per cent. respectively, which is a fairly satisfactory agreement with the P_2O_5 determination actually carried out in the ash.

During the course of our work on opium we have carried out many experiments on the effect of manures. A number of these samples of opium from the differently manured plots have been taken for ash analysis. It was unfortunate that a complete set of samples of all the kinds of manurial treatment was not available. For the details of the actual manurial experiments carried out the reader must be referred to our previous publications.[1] The analyses given below are all of the opium produced by the first lancing of the capsules in each plot.

TABLE V.

Effect of manures on ash constituents of opium.

No. of sample	Manurial treatment	Ash on dry opium per cent.	Percentage on dry ash					
			Sand and silica	P_2O_5	SO_3	CaO	K_2O	Fe_2O_3 Al_2O_3
406	$NaNO_3$ . . .	2·38	13·90	11·33	24·39	4·86	37·87	4·64
478	Do. . . .	2·55	15·14	10·48	24·68	5·39	37·50	3·45
386	Super and $NaNO_3$.	2·23	13·36	13·40	25·58	6·96	38·90	..
466	Do. . . .	2·32	27·82	10·14	20·55	6·90	29·65	..
472	K_2SO_4 and $NaNO_3$.	2·68	22·64	10·73	17·02	5·30	35·02	5·58
475	K_2SO_4 and Super .	2·94	17·79	11·91	24·97	5·90	30·10	..
433	K_2SO_4 and $NaNO_3$ and Super.	2·50	21·17	12·13	22·94	6·83	28·10	..
456	Do. . . .	2·22	19·68	12·61	21·34	9·80	26·87	5·90
427	Cattle manure . .	2·35	16·91	13·94	22·76	6·93	30·36	..
451	Do. . . .	2·85	23·69	11·91	22·29	8·34	26·86	..
445	Castor cake . .	2·15	26·05	13·06	17·33	7·63	28·94	4·84
461	Do. . .	2·54	15·10	12·40	24·96	8·10	29·07	..

[1] *Mem. Dept. Agri. in India, Chem. Ser.*, Vol. VI, No. 2, p. 89.

In any case no very definite conclusions could be drawn from such an incomplete set of analyses, but it does not seem that either phosphate or potash has produced any noticeable effect on modifying the P_2O_5 or K_2O content of the latex

Conclusions.

There is a steady rise in the amount of ash constituents of the latex of the opium poppy at each successive lancing up to the fourth.

There appears little or no increase in later lancings than this.

The composition of the ash appears more or less the same in the case of each successive lancing, and as far as we are able to judge from our results it is not appreciably affected by manuring.

Estimation of sulphate and phosphate carried out on the original opium and not by the ashing process shows that these constituents rapidly increase in the case of the first three lancings. Phosphate determinations have been carried out in six successive lancings and shows a rapid increase up to the fifth lancing but practically no further increase in the sixth lancing. Chlorides appear to be absent from the latex.

The increase in ash constituents of each successive lancing is accompanied by a rapid falling off in total alkaloid content of the latex. This fall in alkaloid content is largely accounted for by a rapid fall in morphine and to a lesser extent by a fall in narcotine content. Codeine and papaverine are present in more or less constant amounts in each successive lancing. It is possible that there is a physiological connection between the rise in ash constituents and the fall in morphine.

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Nitrogen Recuperation in the Soils of the Bombay Deccan, Part I

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NITROGEN RECUPERATION IN THE SOILS OF THE BOMBAY DECCAN, PART I.

BY

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The problem as to how the fertility of Indian soils is maintained in the absence of manure, more particularly in the arid and semi-arid tracts like the Deccan, has always been a difficult one. More especially the maintenance of the available nitrogen is difficult to explain. On the one hand, there is a demand on the accumulated stocks of nitrogen from the crop grown. This reaches, in the case of an annual crop of *jowar* (*Andropogon Sorghum*) grown without manure, to about 20 lb. of nitrogen per annum for such a crop (700 lb. grain and 2,000 lb. straw) as is commonly produced in the Bombay Deccan. Then there is the annual loss from drainage and from denitrification, while the only apparent return of nitrogen to the soil is from the quantity supplied by rain and dew.

This latter quantity is small. According to Leather,[1] who made very extensive observations in North India, the total amount added to the land at Cawnpore, on the average, was 3·25 lb. of nitrogen per acre per annum as rain, and 0·11 lb. as dew*, or a total of 3·36 lb. of nitrogen per acre. This is far less than the annual loss from the crop alone.

It would seem certain, therefore, that, even in the absence of vegetation, there must be considerable fixation of nitrogen from the atmosphere, and evidence to this effect has been obtained by several workers in the Punjab. In the first place, the Agricultural Chemist to the Punjab Government found in 1919[2] a great change in the amount of nitrogen in the land in various parts of that province between May and October, though no canal water was given. On an average the amount of nitrogen in the soil increased by 3 5 per cent. between the months named, but in many cases there was a large loss, while in others there was an equally large increase. The records do not indicate any close connection between, on the one hand, natural or other sterilization of the soil, or, on the other, cultivation, and the fixation recorded. That some fixation takes place seems clear from these results.

[1] Leather, J. W. The Composition of Indian Rain and Dew *Mem. Dept. Agri. India, (Chem. Ser.*, Vol. I, No. 1 (1906).

* The dew was only recorded during the cold weather.

[2] *Report on the Operations of the Department of Agriculture, Punjab*, 1919-20, Part II, p. 164.

More recent results have been recorded by the Punjab workers in 1922.[1] By examination of numerous samples of soil from the field, they found that the most marked and uniform fixation of nitrogen with all soils and under all conditions of incubation took place in September, towards the end of the monsoon. There appeared to be a definite seasonal influence which must be taken into account. The fixation was in some cases greater in cultivated soils, and sometimes the reverse. The results were conclusive, however, in showing that it is not until after a long period of dry heat that the soil becomes capable of considerable nitrogen fixation. It also appeared that a period of rapid nitrogen fixation is followed by an almost equally rapid loss.

The experiments which we are about to describe were designed to ascertain, whether and under what conditions an ordinary Deccan soil taken at the end of the hot weather, and kept dry, would fix nitrogen from the air. As the conditions were to be definitely prescribed, the experimental work had obviously to be done in the laboratory. The soil used for the work was obtained from Pashan village, five miles from Poona. It had been cropped every year, but without any leguminous crop or any manure for ten years. There had likewise been no irrigation, and the annual crop was either *bajri* (*Pennisetum typhoideum*) or *jowar* (*Andropogon Sorghum*). It was a typical "medium black soil" of the Deccan and when air-dry gave the following determinations :—

	Per cent.
Moisture (given off at 98°C.)	6·6
Loss on ignition (excluding moisture given off at 98°C.)	11·4
Nitrogen	0·031

On analysis, by extraction with concentrated hydrochloric acid, the following figures were obtained, based on the air-dry fine soil :—

	Per cent
Sand	58·4
Ferric oxide (Fe_2O_3)	11·9
Alumina (Al_2O_3)	6·5
Lime (CaO)	4·0
Magnesia (MgO)	1·6
Potash (K_2O) and Soda (Na_2O)	0·4
Phosphoric acid (P_2O_5)	0·07

It will be seen that the nitrogen contained in this soil is very small in amount (0·031 per cent.). As all results depended on variations of this amount great care had to be taken as to the accuracy of this determination. The methods adopted are indicated in the appendix, but check determinations showed that the greatest error that is likely to occur is 0·00085 per cent., or 0·85 mg. per 100 grm. of soil.

Experimental work.

First Series.

To begin with, it was decided to find out the effect on the nitrogen of the soil of varying the quantities of moisture, and also of varying the temperature and the

[1] Wilsdon, B. H., and B. Ali. Nitrogen Fixation in Arid Climates. *Soil Science*, Vol. XIV, No. 2, p. 127 (1922).

light conditions of the soils, and also the effect of additional lime in each of these cases. One thousand grammes of soil were properly mixed with water to make up the necessary percentage of moisture and kept in trays eight inches in diameter and two inches in height. The loss of moisture was daily made up by adding a fine spray of water to ensure equal distribution. In taking samples for analysis the whole of the soil in the tray was thoroughly mixed and the necessary quantity of the soil taken for examination. In the first series of trials the organic and ammoniacal nitrogen alone was estimated but not the nitrite and the nitrate. The percentage of nitrogen is throughout expressed on soil dried in a steam oven at 98° C. The soil was analysed on the first day and then at intervals of thirty-five days as it was thought that smaller intervals might not show any appreciable change. Four sets of the following soils were prepared :—

(1) Soil containing 6·6 per cent. moisture (ordinary air-dry soil).
(2) Soil containing 20 per cent. moisture.
(3) Soil containing 30 per cent. moisture.

Each of these had a corresponding sample containing 3 per cent. additional lime ($CaCO_3$) with the exception of the ordinary air-dry soil.

One of these four sets was kept in an incubator maintained at 20°C. A second set was kept in an incubator maintained at 40°C. The third one was kept in diffused light near the glass window of a room free from laboratory fumes and gases. Care was taken to see that direct sunlight never fell on this set of trays. For the first three months of the exposure the temperature varied from 20°C. to 27°C., while during the next three months the room temperature varied from 27°C. to 35°C. Thus the minimum was 20°C. or more and the maximum was less than 40°C., and the temperature of this set of soils was, therefore, between the other two temperatures at which the trays in the first two sets were kept. The fourth or the last set of trays was kept in the open, covered with glass plates and exposed to the sun with the usual variations in the light.

Effect of the varying quantities of moisture. The following table gives the milligrammes of organic and ammoniacal nitrogen per 100 grm. of soil kept at 20°C. in the incubator.

TABLE I.

	1st day	After 35 days	After 70 days	After 105 days	After 140 days	After 175 days
	Milligrammes per 100 grm. of soil.					
Soil containing 30 per cent. moisture.	33·01	48·55	35·18	30·73	25·00	26·21
Soil containing 20 per cent. moisture.	33·01	42·00	33·79	30·77	..	23·93
Soil containing 6·6 per cent. moisture.	33·01	31·38	29·80	25·61	22·64	..

From the above table it is evident that the higher the quantity of water the higher is the amount of nitrogen fixed. It seems that during the first thirty-five days nitrogen is fixed and then during the next period the amount decreases. After this also it continues to go down up to at least 175 days. It must be remembered that the figures represent the algebraic sum of the fixation and the loss of nitrogen, since both of these actions are likely to go on side by side. It is also possible that the smaller figures may be due to nitrification.

A similar effect of exposure in the moist condition is shown in the trays kept at 40°C. (Fig. 1).

TABLE II.

	1st day	After 35 days	After 70 days	After 105 days	After 140 days	After 175 days
	Milligrammes per 100 gm. of soil.					
Soil containing 30 per cent. moisture.	33·01	55·01	40·49	33·88	30·31	19·52
Soil containing 20 per cent. moisture.	33·01	44·31	39·69	26·22	27·75	23·25
Soil containing 6·6 per cent. moisture.	33·01	35·21	33·94	21·68	26·56	23·53

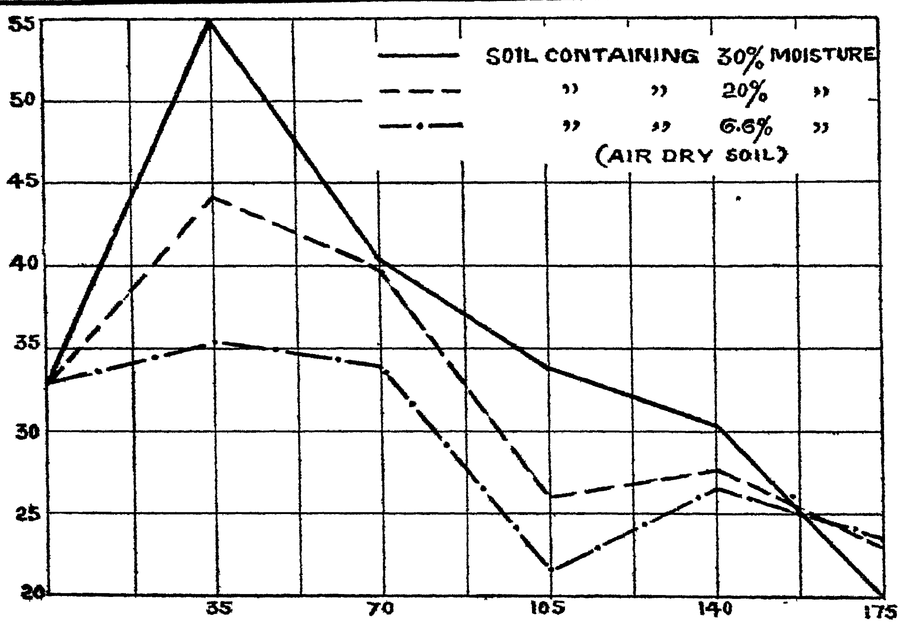

FIG. 1.

In the trays exposed to diffused light and those in the open air conditions, the same tendency was shown.

TABLE III.

	After 35 days	
	Exposed to diffused light	Exposed to open air
	Milligrammes per 100 grm. of soil.	
Soil containing 30 per cent. moisture	49·98	43·61
Soil containing 20 per cent. moisture	47·07	44·01
Soil containing 6·6 per cent. moisture	38·14	39·17

With soils containing three per cent. additional lime similar results were obtained.

TABLE IV.

	At 20°C. after 35 days	At 40°C. after 35 days	Exposed to diffused light after 35 days	Exposed to open air after 35 days
	Milligrammes per 100 gm. of soil.			
Soil containing 30 per cent. moisture . .	48·29	44·09	44·48	44·05
Soil containing 20 per cent. moisture . .	38·33	40·52	40·20	41·56
Soil containing 6·6 per cent. moisture .	..	..	34·82	41·41

Effect of temperature. The trays kept at 20°C. represent a low temperature, those at 40°C. represent a high temperature, while those kept in diffused light were between 20° and 27°C. for the first three months and therefore represent an intermediate stage. After 35 days all the samples show a fall in the nitrogen contents, and hence the figures for the first 35 days only are shown in the following table. The figures are in milligrammes of organic and ammoniacal nitrogen in 100 grm. of soil.

TABLE V.

	Soil without lime			Soil with 3% additional lime		
	30 per cent moisture	20 per cent moisture	6 6 per cent moisture	30 per cent moisture	20 per cent moisture	6 6 per cent moisture
	Milligrammes per 100 grm. of soil					
40°C.	55 01	44 31	35 21	44 09	40 52	
Diffused light . .	49 98	47 07	38 14	44 48	40 20	34 82
20°C.	48 55	42 00	31 38	48 29	38 33	

These figures clearly indicate that the largest quantity is fixed at a temperature above 20°C., but at 40°C. it is lower than at temperatures between 20°C. and 27°C. It seems that a high temperature like 40°C. slackens the activity of fixing nitrogen or hastens nitrification.

Effect of additional lime. First set. To find out the effect of additional lime, three per cent of calcium carbonate was added to the soil although it already contained excess of calcium carbonate. The effect is shown by the figures given below. Only the fixation during the first 35 days is given, since, as in other cases, the nitrogen begins to decrease after that period.

TABLE VI.

	30 per cent moisture		20 per cent moisture		6 6 per cent moisture	
	20°C	40°C	20°C	40°C	Diffused light	Open air
	Mg per 100 grm of soil					
Without additional lime	48 55	55 01	42 00	44·31	38 14	39 17
With 3 per cent additional lime	48 29	44 09	38 33	40 52	34 82	41 41

The effect of lime, from these figures, seems slightly to check the fixation of nitrogen, but it is just possible that more nitrification takes place by the addition of lime and what is lost as organic and ammoniacal nitrogen may be gained as nitrite and nitrate nitrogen. Hence without determining the nitrites and the nitrates nothing can be definitely stated with regard to the effect of lime from these figures.

Second set. In the first set of experiments it was seen that when only the organic and ammoniacal nitrogen determinations were made the additional lime did not show any advantage. It was thought that this possibly occur ed because the soil with additional lime had more nitrite and nitrate nitrogen. In order to make the point clear a new set of soils was prepared and exposed and nitrogen in the nitrite and nitrate form was determined along with the organic and ammoniacal nitrogen.

Soils containing 30 per cent. moisture were kept at 40°C. From the following figures it seems that additional lime brings about more nitrification, but the total nitrogen throughout the period of 84 days is greater in the original than in the same soil with additional lime.

TABLE VII.

No. of days	Organic and ammoniacal nitrogen		Nitrite and nitrate nitrogen		Total nitrogen	
	Without additional lime	With additional lime	Without additional lime	With additional lime	Without additional lime	With additional lime
	Mg. per 100 grm. of soil.					
1st day	34·25	..	0·189	..	34·44	..
14 days	41·03	39·99	0·259	0·543	41 29	40·53
28 days	52·60	49·34	0·553	0·582	53·15	49·94
35 days	53·65	51·59	0·595	0·741	54 24	52·33
42 days	47·65	47·19	0·655	0·356	48·20	47·55
56 days	46·19	46·18	0·966	0·555	47·16	46·73
70 days	43 71	43·72	0·638	0 784	44 35	44·50
84 days	42·50	37·06	0 583	1 000	43·08	38·06

Effect of light. From the results obtained during the experiments no definite relation of the increase of nitrogen to the intensity of light can be shown, but it is certain that even in darkness the fixation goes on.

Trays of soil samples kept outside were covered with sheet glass to prevent any soil from being blown away, and to prevent outside material being deposited on to the soil. The soils kept in these trays did not show any striking results compared with the results obtained from trays kept in diffused light or in darkness.

From the experiments so far recorded the following conclusions may be drawn :—

1. When a Deccan black soil, which has been collected dry in the hot weather, is moistened and exposed to air, rapid increase in the amount of organic and ammoniacal nitrogen takes place.
2. This increase in the amount of nitrogen is purely temporary. On maintenance of the conditions for more than thirty five days, there is again a continuous fall in the organic and ammoniacal nitrogen. Whether this is due to disappearance of the nitrogen or to its conversion into nitrites and nitrates, the experiments so far recorded do not show.
3. The larger the amount of water present (at least up to 30 per cent.), the greater the increase in the amount of nitrogen.
4. A rise in temperature from 20°C. to 40°C. corresponds with increased fixation of nitrogen. But it is probable that the optimum is below the latter temperature.
5. Increase in nitrogen takes place both in the presence or absence of light.

6. The addition of lime to the soil in question (already containing an excess of lime) does not show any greater nitrogen fixation.

Second Series.

The second series of experiments was started to determine chiefly two points. The first of these was as to the time required by the soil to reach the highest quantity of nitrogen content, and the second was to find out whether the fall in organic and ammoniacal nitrogen was due to nitrification or to actual loss of nitrogen from the soil. In this series the moisture content for all the samples was kept at 30 per cent. and nitrite and nitrate nitrogen was determined along with the organic and ammoniacal nitrogen. The determinations were made at intervals of ten days.

Four similar samples were under experiment at the same time. One of these was maintained at a constant temperature of 20°C., a second at a constant temperature of 40°C., a third in diffused light at the laboratory temperature and the fourth in open air. The results obtained are given below. In this table the total nitrogen includes the nitrite and the nitrate nitrogen, separately determined. (Fig. 2.)

Table VIII.

	Original nitrogen	10 days Organic and ammoniacal nitrogen	20 days Total nitrogen	30 days Total nitrogen	35 days Total nitrogen	45 days Total nitrogen	55 days Total nitrogen
	Mg. nitrogen in 100 grm. of soil.						
20°C. . .	31·21	38 56	39 62		39 26	37 69	36 54
40°C. . .	.	38 71	39 15	41 40	43 37	39 66	38 63
Diffused light	.	39 37	41 10	40 40	41 52	37 77	37 14
Open air . .		39 67	40 11	40 06	40 38	37 71	36 58

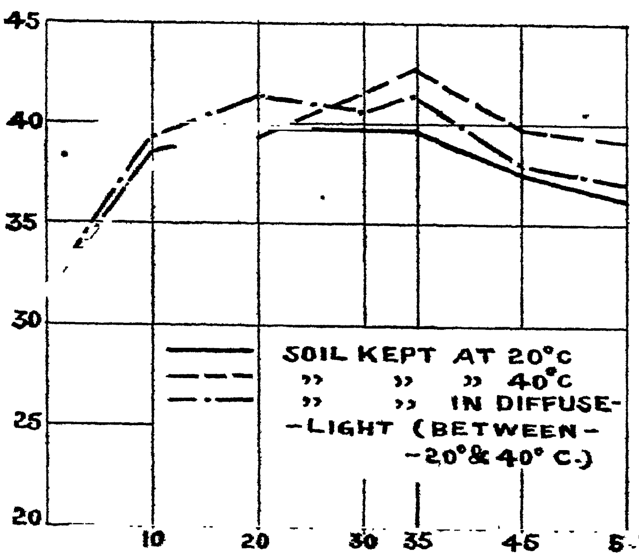

Fig. 2.

From this table it can be seen that when water is added, within ten days a large quantity of nitrogen is fixed, and this goes on increasing till about thirty-five days, and then begins to fall. Since in the above table total nitrogen is given, it is clear that the whole of the fall in nitrogen that was observed in the first series and which is again shown in the above series was not due to nitrification, but, in part at least, was caused by the loss of nitrogen from the soil. In the first series the soil in the diffused light which was at a lower temperature than 40°C. showed higher nitrogen accumulation than soil kept at 40°C., but in this series, where total nitrogen is determined, the soil at 40°C. shows a greater increase in this constituent.

The figures for nitrite and nitrate nitrogen are also interesting. The figures given in the following table represent the sum of the nitrite and the nitrate nitrogen.

TABLE IX.

	Original nitrogen	After 20 days	After 30 days	After 35 days	After 45 days	After 55 days
		Mg. nitrogen per 100 grm. of soil.				
20°C.	0·2[illegible]	0·21	0·42	0·59	0·79	0·41
40°C.	0·20	0·77	[illegible]·77	[illegible]·92	0·[illegible]2	0·7[illegible]
Diffused light . . .	0·20	0·1[illegible]	0·39	0·40	0·58	0·38
Open air	0·20	[illegible]·41	0·55	0·58	0·55	0·56

The formation of the nitrite and nitrate nitrogen goes on steadily increasing up to 45 days, and it is only after that, that the quantities begin to fall. This loss may be due to the escape of free nitrogen. The quantities of nitrite and nitrate nitrogen reach the highest figure 10 days after the highest figure for organic and ammoniacal nitrogen.

In the first series it was observed that the highest figures for organic and ammoniacal nitrogen were less for soils at 40°C. than for soils in diffused day light where the temperature was less than 40°C. It was not clear then whether this was due to smaller activity of fixation or due to greater nitrification, but from the above it can be said without doubt that there is greater nitrification at 40°C. than at lower temperatures, and this explains as to why in the previous experiments lower figures were obtained for soils at 40°C. than for soils at a lower temperature.

The conclusions of this series of experiments may be put down as follows :—

(1) The highest amount of fixed nitrogen is obtained after about thirty-five days from the time of moistening the soils. This confirms the results

obtained in the first series. Nitrification goes on after thirty-five days, but the total amount of nitrogen is highest at about thirty-five days.

(2) The highest figure for nitrite and nitrate nitrogen is obtained at about forty-five days after the commencement of the experiments.

(3) The fixation of nitrogen is higher at 40°C. than at lower temperatures. At this temperature nitrification is also greater than at lower temperatures.

THIRD SERIES.

In the first two series it was found that after about thirty-five days from the time of exposing the samples, the highest figure for increase of nitrogen was obtained and after that there was a regular fall. When the soil was taken for experimental purposes it was air-dry containing about 6 per cent. water, and it was this soil that showed fixation when water was added. It seems, therefore, that when a dry soil gets water it begins to show this activity of fixing nitrogen. In order to find out the extent to which this property proves to be useful in increasing the nitrogen contents of the soil a third series of experiments was taken up. In this case the soil was given water to make up to 30 per cent. and 20 per cent. of moisture respectively, and the samples were then allowed to accumulate nitrogen. Determinations of nitrogen were done at an interval of two weeks. When the nitrogen contents began to show a fall, the soil was quickly dried by spreading in a thin layer on a water-bath and stirring. Care was taken not to allow the temperature of the soil to go beyond 60°C. To this dried soil, water was added to make up the necessary moisture, and the soil was allowed to increase its nitrogen content. This process was repeated twice after which the soil did not show any increase in nitrogen assimilation.

TABLE X.

	Original nitrogen	14 days	28 days	42 days
	Mg. nitrogen per 100 grm. of soil.			
Soil containing 30 per cent. water . .	31·21	41·30	42 88	40 32
Soil containing 20 per cent. water .	31·21	41·29	41 59	39 17

As in the previous experiments, the nitrogen contents increased in the beginning. On the forty-second day the nitrogen was less than on the twenty-eighth day, which meant that it had reached its highest point and had started coming down. The soil was, therefore, dried at this stage and kept with water added, and analysed as usual.

TABLE XI.

	14 days after first drying	28 days after first drying	42 days after first drying		14 days after second drying	28 days after second drying
	Mg. nitrogen per 100 grm of soil.				*Mg. nitrogen per 100 grm. of soil.*	
Soil containing 30 per cent. moisture.	42·93	44·77	38·27	Dried second time	34·77	31·52
Soil containing 20 per cent. moisture.	40·00	41·69	37·52		31·04	..

After the first drying the nitrogen contents began to increase and reached the highest point between 28 and 42 days after keeping the soils the second time. The highest point reached in this period was higher than the highest point reached in the first period. When the soils were dried for the second time no increase in total nitrogen could be obtained, and hence the series was closed at the end of four weeks after the second drying.

Although the fixation of nitrogen stopped at the end of four weeks after the second drying, the nitrification continued vigorously all along as can be seen from the following table :—

TABLE XII.

	Original	14 days	28 days	42 days		After first drying				After second drying	
						14 days	28 days	42 days		14 days	28 days
	Mg. of nitrite and nitrate nitrogen per 100 grm. of soil.										
Soil containing 30 per cent. moisture.	0·20	0·66	0·73	0·57	Dried	0·92	1·08	1·45	Dried	2·19	1·57
Soil containing 20 per cent. moisture.	0·20	0·55	0·67	0·73		0·90	1·28	1·33	do.	1·10	..

The conclusions that can be drawn from this series are two :—

(1) When the soil gets water the nitrogen begins to increase for some time and then a fall commences. If at this juncture the soil is dried at 60°C. and then gets moistened again, the nitrogen increases further, for four or five weeks more, and then begins to go down. Repeated drying does not increase the nitrogen contents beyond a certain limit under the given conditions.

(2) The formation of nitrates continues to be on the increase long after the increase in total nitrogen content stops.

Fourth Series.

It is now a matter of wide experience that the soil improves by heating and is able to produce a better crop. In order to find out what extra advantage is obtained, with regard to the nitrogen content of the soil, where burning of the soil is practised a series was arranged in which the soil was previously heated to 100°C. for half an hour. Water was added to make up different percentages and the samples were kept at 40°C. Determination of nitrogen contents was made every second week.

Table XIII.

		Before heating	After heating	14 days	28 days	42 days
		Organic and ammoniacal nitrogen in mg. per 100 grm. of soil.				
30 per cent. moisture	Heated . .	31·01	30·28	40·95	44·77	41·03
	Unheated .	31·01	..	40·64	42·15	39·45

Table XIV.

		Before heating	After heating	14 days	28 days	42 days
		Nitrite and nitrate nitrogen in mg. per 100 grm. of soil.				
30 per cent. moisture	Heated . .	0·20	0·17	0·27	0·31	0·39
	Unheated .	0·20	..	0·66	0·73	0·87

Table XV.

		Before heating	After heating	14 days	28 days	42 days
		Total nitrogen in mg. per 100 grm. of soil.				
30 per cent. moisture	Heated . .	31·21	30·45	41·32	45·08	41·42
	Unheated .	31·21	..	41·30	42·86	40·32

By heating the soil a small quantity of nitrogen is lost, but it is soon made up after the addition of water. The total amount of nitrogen rises a little higher in the heated soil than in the unheated soil.

If, however, the determination of nitrogen in the heated soil is continued beyond forty-two days it is seen that the total nitrogen goes down slowly even though the nitrification is quite rapid.

TABLE XVI.

Heated soil with 30 per cent. moisture.

	42 days	56 days	70 days	84 days	98 days	112 days
	Nitrogen in mg. per 100 grm. of soil.					
Organic and ammoniacal nitrogen.	41·03	40·18	41·36	38·88	35·70	31·29
Nitrite and nitrate nitrogen .	0·39	0·88	1·33	1·46	..	1·13
Total nitrogen . .	41·42	41·06	42·69	40·34	..	32·42

If to the heated soil enough water is not added, more nitrogen than in the unheated soil is not added as will be seen from the following figures :—

TABLE XVII.

		Before heating	After heating	14 days	28 days	42 days
		Total nitrogen in mg. per 100 grm. of soil.				
20 per cent. moisture	Heated . .	31·21	30·45	39·55	41·29	39·87
	Unheated .	31·21	..	41·40	41·47	39·35

General Conclusions.

(1) When water is added to the soil, within ten days a large quantity of nitrogen is fixed and this goes on increasing till about thirty-five days and then slowly begins to decrease.

(2) Upto 30 per cent. of water, the larger the quantity of water the higher is the nitrogen fixed.

(3) The fixation of nitrogen and nitrification are higher at 40°C. than at lower temperatures.

(4) Increase in nitrogen takes place both in the presence and absence of light.

(5) The addition of lime to the soil (already containing enough of lime) does not show any advantge over the original soil in increasing nitrogen fixation, but it facilitates nitrification.

(6) If the soil which has fixed the highest quantity of nitrogen after being moistened gets dried up and then gets moistened again, the nitrogen increases further for four or five weeks more and then begins to go down. Repeated drying, however, does not increase the nitrogen contents beyond a certain limit.

(7) If the soil is heated to 100°C. it loses a small quantity of nitrogen. This however, is soon made up if enough water is added to it, and the total amount of nitrogen fixed in the heated soil is found to be higher than that in the unheated soil.

APPENDIX.

Method of determining Organic and Ammoniacal Nitrogen.

The organic and ammoniacal nitrogen of the soils was determined together by the usual Kjeldahl process. For this, 20 grm. of the soil sample were digested in a Kjeldahl flask with strong sulphuric acid, the digestion being completed by the addition of potassium sulphate. The liquid so digested, after being made alkaline by the addition of a sufficient quantity of caustic soda, was distilled by means of steam and the ammonia evolved was collected in tenth-normal sulphuric acid. The excess of acid was neutralized by tenth-normal caustic potash, using methyl orange as an indicator; and from the amount of tenth-normal sulphuric acid used, after making necessary correction for blanks, the nitrogen content of the sample was calculated.

NITRITE DETERMINATION.

In this determination the Griess Ilosway method was followed. In this method two reagents were used: (1) 0·5 grm. of sulphanilic acid was dissolved by heat in 150 c.c. of dilute acetic acid (1 : 2), (2) 0·1 grm. of alpha-naphthylamine was heated with 20 c.c. of strong acetic acid and mixed with 130 c.c. of dilute acetic acid (1 : 2). These two solutions were kept separate and one c.c. of each of these was added to the solution from which nitrite was to be determined. In the case of soil extracts 50 c.c. of the clear filtrate were used. The red colour was allowed to develop and in every case the same period was allowed for its development and the colour was then compared with standardized tintometer glasses.

A standard solution of sodium nitrite was prepared by dissolving 0·493 grm. in 1,000 c.c. of water. 5 c.c. of this were made to 500 c.c. and from this 25 c.c. were taken for standardizing the tintometer glasses. This method is of great advantage. The nitrite solution does not remain constant as the tintometer glasses and the trouble of preparing the standard solution every now and then is saved, because once the glasses are standardized they remain constant.

NITRATE DETERMINATION.

The phenol-disulphonic acid method was used throughout to determine nitrates. 370 grm. of pure strong sulphuric acid were added to 30 grm. of pure phenol crystals and placed in an Erlenmeyer flask which was submerged in boiling water for six hours. The reagent was then preserved in a stoppered bottle. A standard solution of potassium nitrate was prepared by dissolving 0·722 grm. of pure potassium nitrate (previously heated just to fuse) in water and the solution made upto

1,000 c.c. 1 c.c. of this, containing 0·1 mg. was used for standardizing the yellow coloured glasses of the tintometer. The nitrate solution keeps well, yet the tintometer is used because it is more convenient. In each determination 50 c.c. of the clear extract of the soil were evaporated just to dryness in a porcelain dish on a water bath, with two drops of a saturated solution of sodium carbonate being previously added. When it is dry it is dissolved in water to 90 c.c and 10 c.c. of ammonia (1 : 2) were added. After shaking the cylinder and allowing the yellow colour to develop in every case for the same period, the quantity of nitrate was calculated by comparison with the standard tintometer glasses.

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The Determination of Available Phosphoric Acid of Calcareous Soils

Part I. Inapplicability of Dyer's Method to Highly Calcareous Soils

Part II. Extraction of Phosphoric Acid of Calcareous Soils with Salt Solutions

Part III. Potassium Carbonate Method for Estimation of Available Phosphoric Acid of Highly Calcareous Soils

BY

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THE DETERMINATION OF AVAILABLE PHOSPHORIC ACID OF CALCAREOUS SOILS.

PART I.

Inapplicability of Dyer's Method to Highly Calcareous Soils.

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(Received for publication on 9th June 1925.)

The value of weak acid solvents has generally been recognized by all agricultural chemists as a means of evaluating the "available" potash and phosphoric acid in soils. The importance of this method of analysis lies in the fact that it affords a distinction between those phosphorous compounds which are fairly easily soluble and may therefore be expected to become readily available as plant food, and the less soluble compounds which are of less value to the nutrition of plants. But it is generally conceded that the method is an empirical one, and its usefulness lies in the correlation of the analytical values obtained with the response of ordinary soils to a manurial treatment based on these values.

The method had its origin in the conception of the plant root as a special excreting agent capable of liberating acids which attack the soil constituents, and, by dissolving them, bring them into a form to be readily assimilated by the plant. With this conception in view Dyer[1] examined the root-sap acidity of 20 different natural orders of plants and found it to be on the average 0·91 per cent. in terms of citric acid. He, therefore, proposed 1 per cent. citric acid solution as the standard to be employed for the estimation of available potash and phosphoric acid in soils. Since then the use of citric acid has been widely accepted for this purpose, although in later years other acids of different strengths have come into use.

The conception of the plant root as an excreting and dissolving agent which gave rise to the above methods is now generally abandoned, as no trustworthy evidence can be obtained that any acid other than carbon dioxide is excreted, or that any action beyond respiration is concerned. However, the general principle underlying them is the extraction of soils with acids of low concentration, and their value lies in their correlation with the results of cropping and manurial treatments.

[1] *Trans. Chem. Soc.*, 1894, **65**, 115.

The application of Dyer's method of analysis to highly calcareous soils results in the neutralization of much of the citric acid used, and the values obtained in these circumstances have been received with suspicion by many chemists. Dyer himself, in a postscript to his paper (loc. cit.), recommended that in such cases an extra amount of citric acid equivalent to the quantity of calcium carbonate present might reasonably be added to the solution.

Wood[1] and Leather[2], when employing such extra amount of acid, found that the results obtained were not borne out by actual farm practice or pot-cultures; but Cousins and Hammond[3], from experiments on bananas, adduce evidence diametrically opposed to their conclusion. Stenius[4], using extra amount of citric acid, found that the basicity has a decidedly depressing influence on the solvent power of citric acid for available P_2O_5. His results do not lend support to the contentions of Cousins and Hammond.

Hall and Plymen[5] added to soils 2-10 per cent. calcium carbonate as finely-powdered Iceland Spar, and found that the citric acid, as it was neutralized by $CaCO_3$, extracted less and less phosphoric acid, until with 10 per cent. $CaCO_3$, which is more than what is required for complete neutrality, the amount dissolved approximated to that dissolved from the soil by carbon dioxide alone. They held that in the light of more extended experience it might be found necessary to adopt different limits for soils of different types.

Sen[6], following a similar line of investigation, demonstrated that the addition of increasing amounts of $CaCO_3$ to non-calcareous soils resulted in decreasing amounts of P_2O_5 being extracted by 1 per cent. citric acid solution, and concluded that the method could not be relied upon to determine the limits of fertility of calcareous soils.

Similarly, Ramsay[7] found that the presence of $CaCO_3$ in tricalcium phosphate materially reduced the percentage of P_2O_5 extracted when the standard method of extraction with citric acid was applied to the mixtures.

Davis[8], in his study of the calcareous soils of Bihar, has shown that soils containing practically the same amounts of lime may give extraordinary differences in the values of available P_2O_5 extracted by Dyer's method and that soils with a very high proportion of lime may give much higher values than soils with a far smaller proportion of lime. He thus holds the opinion that the varying values obtained with such calcareous soils give a good indication of their fertility and probable manurial reaction. This argument is not, however, convincing, for the fact remains that the majority of North Bihar calcareous soils yield such extremely

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1 *Trans. Chem. Soc.*, 1896, 287.
2 *Mem. Dept. Agri. India, Chem. Series*, Vol I, No. 4, 1907.
3 *Analyst*, 1903, **28**, 230.
4 *Jour. Indus. and Engin. Chem.*, March 1, 1919.
5 *Trans. Chem. Soc.*, 1902, 117-144.
6 *Agri. Jour. India*, April, 1917.
7 *Jour. Agri. Sc.*, Vol. IX, 1917.
8 *Indigo Publication* No. 1, Pusa, 1918.

low values of available phosphoric acid that if any reliance has to be placed upon them, the action of phosphatic manures on them should be well defined and distinctly positive, whereas in actual farm practice it is found that their action is extremely erratic. The application of superphosphate alone, more often than not, yields disappointing results, and the best yields are usually obtained in conjunction with green-manuring.

The trend of such observations as are available, judged in the light of experience, led the writer to the conclusion that with highly calcareous soils there is no definite correlation between the available phosphoric acid determined by Dyer's method and the manurial reactions obtained, and that the method is of very dubious value under these conditions. This should be obvious from a consideration of the facts that the composition of the extracting liquid changes considerably in character with the proportions of $CaCO_3$ present, and that, as shown by Hall and Amos[1], the amount of a soil constituent which passes into solution depends not only on its nature, but also on its mass.

The composition of the extract of a soil when treated with any solvent depends upon the following factors :—

1. The mass of the mineral constituents exposed to the solvent and their solubility under the conditions of the extraction, and the nature of the solvent.
2. The effect of the solvent upon the soil particles protecting or enclosing the minerals.
3. The power of the soil to fix or adsorb the dissolved substances from the solution.

Consequently, it appeared desirable to make a more detailed study of the effect of increasing proportions of $CaCO_3$ in a soil on the amounts of the "available" phosphoric acid determined by Dyer's method than had been done by Sen (loc. cit). The latter increased the proportions of added $CaCO_3$ by increments of 5 per cent. up to a maximum of 40 per cent., but in the present investigation these increments were materially decreased so as to follow the effect more closely up to a maximum addition of 25 per cent.

The soil selected was obtained from Kalianpur and was found to contain a considerable amount of available P_2O_5 as determined by Dyer's method and a very small proportion of $CaCO_3$. The physical and chemical characteristics of this soil as well as of the Pusa soil employed in this investigation are given in a paper published by Harrison and Das[2]. At the same time Sen's experiments of mixing Kalianpur and Pusa soils were repeated, but in this case the available potash was not estimated.

The results obtained from the application of Dyer's method to the several mixtures are given in the following tables.

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[1] *Trans. Chem. Soc.*, 1906, 89, 205.
[2] *Mem. Dept. Agri., India, Chem. Series*, Vol. V, No. 9, 1921, 210-211.

Table I.

Showing the effect of increasing proportions of $CaCO_3$ added to Kalianpur soil on the available P_2O_5 and K_2O extracted by Dyer's method.

Per cent. $CaCO_3$	Grm. available P_2O_5 per 100 grm. mixture (*found*)	Available P_2O_5 present (*calculated*)	Per cent. P_2O_5 extracted	Grm. available K_2O per 100 grm. mixture (*found*)	Available K_2O present (*calculated*)	Per cent. K_2O extracted
0	0·3343	——	100·0	0·0341	——	100·0
2	0·2690	0·3276	82·1	0·0290	0·0337	86·1
4	0·2046	0·3206	64·1	0·0264	0·0330	80·0
5	0·1835	0·3176	57·8	0·0239	0·0327	73·1
6	0·1279	0·3142	40·7	0·0199	0·0323	61·6
7	0·0363	0·3109	11·7	0·0142	0·0320	44·4
8	0·0257	0·3076	8·4	0·0160	0·0316	50·6
9	0·0231	0·3042	7·6	0·0153	0·0313	48·9
10	0·0194	0·3009	2·1	0·0142	0·0310	45·8
12	0·0109	0·2942	3·7	0·0152	0·0303	50·2
14	0·0088	0·2875	3·1	0·0155	0·0296	52·4
16	0·0049	0·2808	1·7	0·0147	0·0289	50·9
18	0·0031	0·2741	1·1	0·0157	0·0282	55·7
20	0·0025	0·2674	0·9	0·0141	0·0275	51·3
25	0·0017	0·2507	0·7	0·0134	0·0258	52·0

In the above experiments the Kalianpur soil was mixed with pure $CaCO_3$ containing no P_2O_5 and the comparisons are therefore easy to determine. In the case of the experiments where the Kalianpur soil was mixed with Pusa soil, the amount of P_2O_5 extracted from the mixtures becomes a proportion of the two soils and the comparisons are not so easy to determine. The results obtained are given in the following table.

Table II.

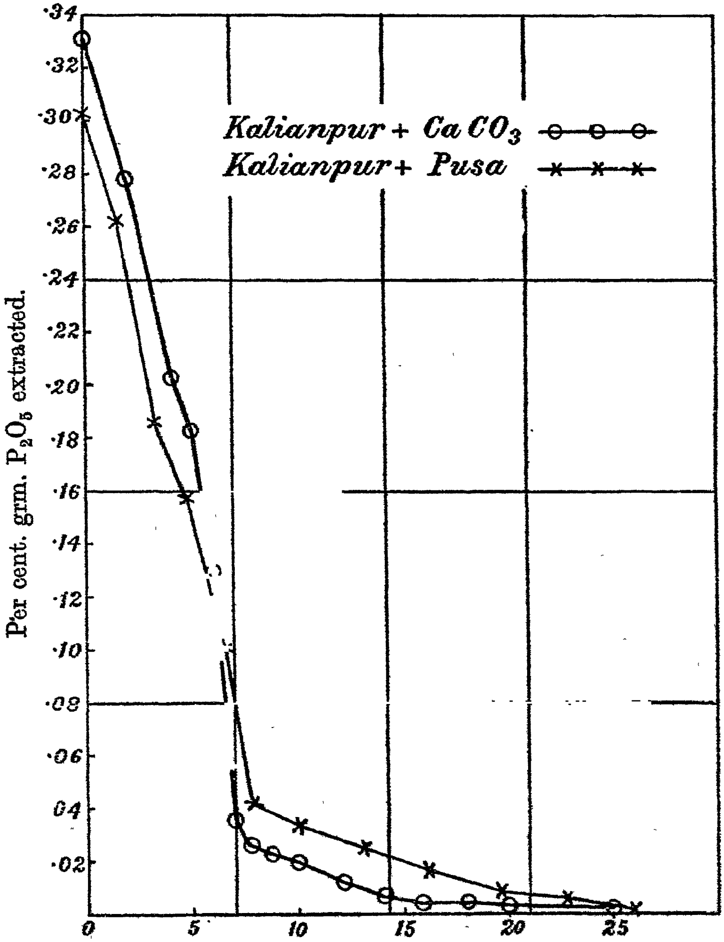
Showing the effect of increasing proportions of Pusa soil added to Kalianpur soil on the available P_2O_5 extracted by Dyer's method.

Per cent. Kalianpur soil	Per cent. Pusa soil	Per cent. $CaCO_3$ equivalent to per cent. Pusa soil in the mixture	Per cent. available P_2O_5 in soil mixture (*found*)	Per cent. available P_2O_5 from 1st and last experiments (*calculated*)	Per cent. P_2O_5 extracted
100	nil	(*in Kalianpur soil* 0·28)	0·3034	——	100·0
95	5	1·63	0·2628	0·2889	91·0
90	10	3·25	0·1852	0·2743	67·5
85	15	4·88	0·1586	0·2598	62·7
80	20	6·50	0·1005	0·2452	41·0
75	25	8·13	0·0410	0·2307	17·7
70	30	9·75	0·0353	0·2161	16·4
60	40	13·00	0·0250	0·1870	13·4
50	50	16·25	0·0158	0·1579	10·0
40	60	19·50	0·0085	0·1288	6·6
30	70	22·75	0·0061	0·0907	6·1
20	80	26·00	0·0028	0·0706	4·0
Nil	100	32·50	0·0004	0·0124	3·2
Nil*	100	32·50	0·0124	0·0124	100·0

* In this experiment sufficient citric acid (*i.e.*, 45·46 grm.) to neutralize 32·5 grm. of $CaCO_3$ present in the soil + 1 per cent. excess citric acid, all dissolved in 1 litre solution, was used.

DIAGRAM I.

Showing the curves produced by plotting per cent. $CaCO_3$ present as such or in the form of Pusa soil in the mixtures against per cent P_2O_5 extracted.



Per cent. $CaCO_3$ present in mixture.

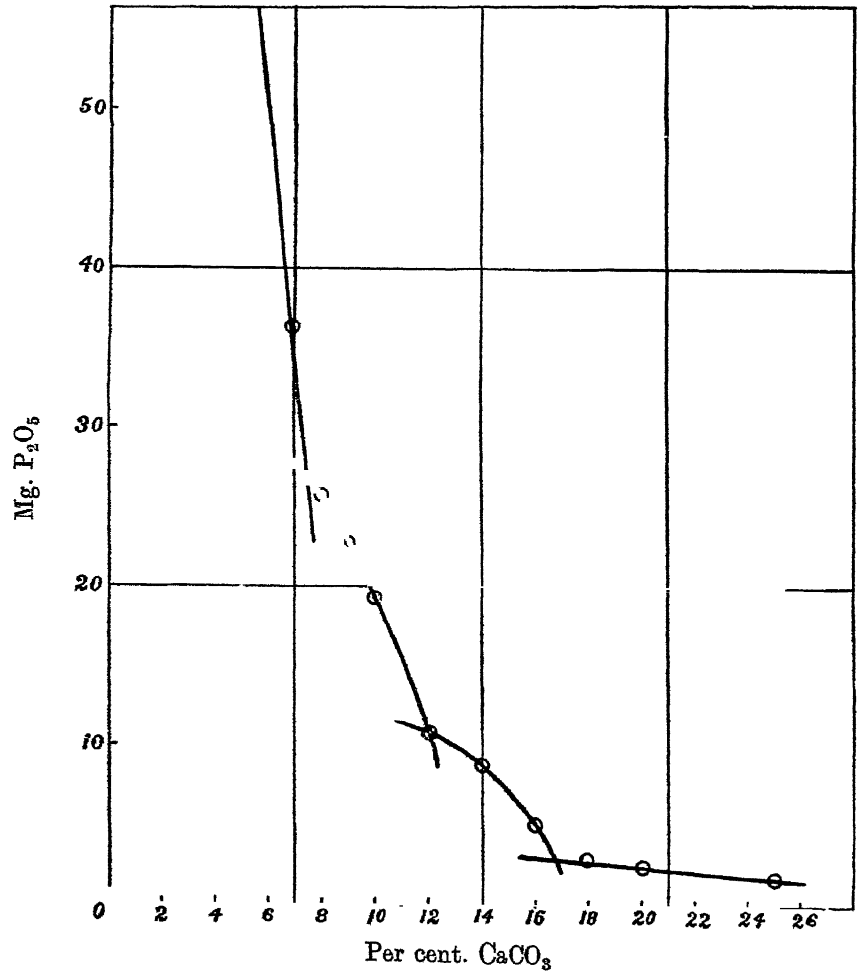
The curves very clearly show the similarity of the results obtained when the $CaCO_3$ is added as such or in the form of Pusa soil. It is evident that the main determining factor is the amount of $CaCO_3$ present, but the continuity of effect is not apparent.

It is found that there is a rapid falling off in the amount of P_2O_5 extracted until there is between 7 and 8 per cent $CaCO_3$ present, above which value the reduction becomes less pronounced.

When, however, the values obtained with over 7 per cent. $CaCO_3$ present are plotted on a larger scale, the breaks in the curve are made more pronounced. This is shown in the following diagram.

DIAGRAM II

Showing a larger scale plotting of the P_2O_5 extracted against per cent $CaCO_3$ present.



The broken nature of the curve suggests that the values obtained for P_2O_5 vary according to the character of the solvent solution, and it is possible from the curves to approximately determine the phases which control the extractions concerned. With gradually increasing amounts of $CaCO_3$ the solutions resulting from the inter-

action of $CaCO_3$ with a citric acid solution of definite volume and strength show the following changes :—

1. A strongly acid solution.
2. A series of solutions of decreasing acidity with increasing amounts of CO_2 and saturated with respect to calcium citrate, up to about 7 per cent. $CaCO_3$, marking the point at which the citric acid is completely neutralized.
3. A saturated solution of calcium citrate with decreasing amounts of free CO_2 and increasing proportion of calcium bicarbonate, from about 7-12 per cent. $CaCO_3$.
4. A saturated solution of calcium citrate with increasing concentration of calcium bicarbonate, from about 12-16 per cent. $CaCO_3$.
5. A solution of approximately constant composition with respect to calcium citrate and bicarbonate, from 16-25 per cent. $CaCO_3$ or upwards.

It will be shown in the sequel that the extraction of the Kalianpur soil with solvents approximating in composition to the phases mentioned above yields results commensurate with those obtained from the corresponding soil mixtures. For the present, however, it may be taken that the application of the Dyer's method for the estimation of available phosphoric acid in calcareous soils is, in effect, an extraction with a series of dissimilar solutions, the composition of which depends mainly upon the amount of $CaCO_3$ present.

When the composition of these solutions is carefully considered in detail, it is evident that two main phases are concerned :—

(i) A phase of decreasing acidity with an approximately constant Ca-ion concentration ; and

(ii) A phase of a series of solutions with an increasing Ca-ion concentration.

It would seem probable, therefore, that by plotting the logarithm of the percentage of $CaCO_3$ against the logarithm of milligrams P_2O_5, two definite curves would be produced. That this is the case is shown in the following diagram.

The graph, which consists of two distinct parts, clearly shows that the extraction of the P_2O_5 is not affected by a uniform set of factors, but that one set of factors operate up to the point when the percentage of $CaCO_3$ reaches between 6 and 7 per cent., and above this point a different set of factors affect the extraction. The variations of individual determinations from the straight line curve may also be considered to be due to the minor changes of composition in the several solutions.

From this it follows that in the case of mixtures of Kalianpur soil with $CaCO_3$ the changes are approximately governed by the mathematical relation—

$$\log P = a - b \log C,$$

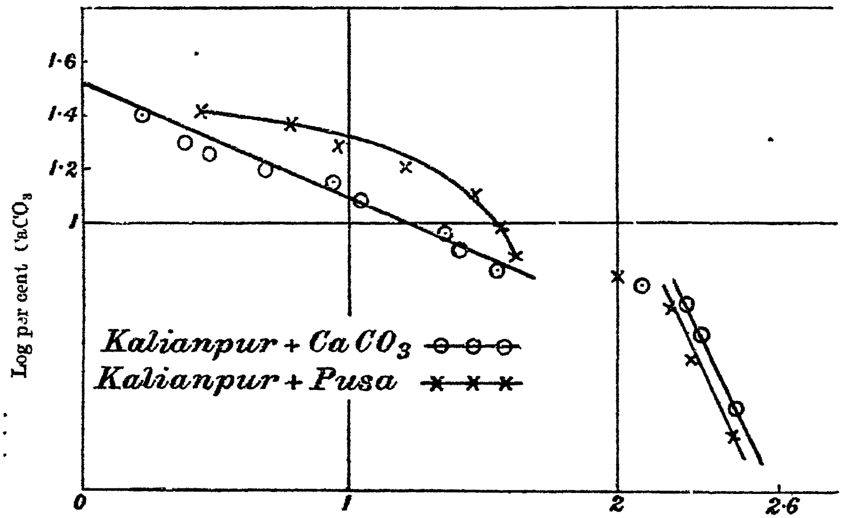
where P=mg. P_2O_5 extracted,

C= per cent. $CaCO_3$ present, and

a and b are constants.

DIAGRAM III.

Showing the curves produced by plotting log per cent. $CaCO_3$ against log mg P_2O_5.



In the *first stage* the values for a and b are 2·573 and 0·4963, and for the *second stage* 3·455 and 2·267 respectively. The variations between the experimental and the calculated values are shown in the following table.

TABLE III.

Showing the calculated and the experimental values of P_2O_5 extracted from mixtures of Kalianpur soil with $CaCO_3$.

Per cent. $CaCO_3$	P_2O_5 calculated	P_2O_5 found	Difference
1st stage. log P=2·573—0·4963 log C			
2	0·2652	0·2690	+0·0038
4	0·1881	0·2046	+0·0165
5	0·1683	0·1835	+0·0152
6	0·1537	0·1279	—0·0258
2nd stage log P=3·455—2·267 log C			
7	0·0346	0·0363	+0·0017
8	0·0256	0·0257	+0·0001
9	0·0196	0·0231	+0·0035
10	0·0154	0.0194	+0.0040
12	0·0102	0·0109	+0·0007
14	0·0072	0·0088	+0·0016
16	0·0053	0·0049	—0·0004
18	0·0041	0·0031	—0·0010
20	0·0032	0·0025	—0·0007
25	0·0019	0 0017	—0·0002

The mathematical relation given above is capable of being expressed as follows :—

$$P = A.C^{-b}$$

or

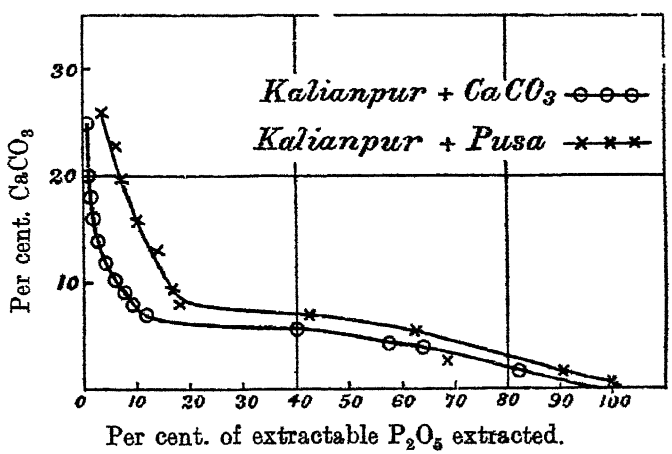
$$P.C^{b} = A.$$

This resembles the well-known Poisson's equation for the adiabatic expansion of gases. The curve produced on plotting P against C as shown in Diagram I conforms approximately to this equation.

In the case of mixtures of Kalianpur and Pusa soils a relationship of this type is not apparent, but it should be borne in mind that the latter soil itself contains an appreciable amount of P_2O_5, which is extractable by solution containing free citric acid. Therefore, the experimental results are subject to the effect of factors which do not operate in the case of mixtures of Kalianpur soil with $CaCO_3$. Nevertheless, it is evident that the main determining factor in both cases is the proportion of $CaCO_3$ present. This is also confirmed when the per cent. of extractable P_2O_5 extracted from both kinds of mixtures is plotted against the values of per cent. $CaCO_3$ present as such or in the form of Pusa soil, from Tables I and II respectively. The following diagram demonstrates this.

DIAGRAM IV.

Showing the curves produced by plotting per cent. $CaCO_3$ present against per cent of extractable P_2O_5 actually extracted.



That adsorption does not control the phenomena is demonstrated by the fact that the amount of P_2O_5 extracted varies according to the time of extraction, all other things being equal. The results are shown in the following table.

TABLE IV.

Showing the effect of time on the extraction of P_2O_5 by Dyer's method.

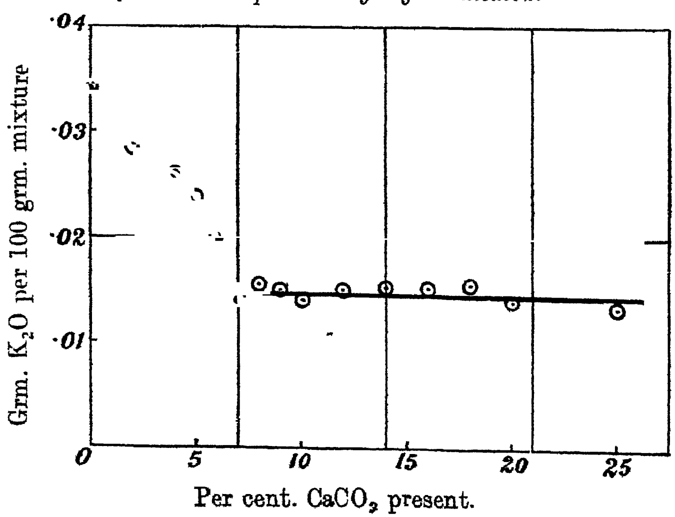
Per cent. $CaCO_3$ in soil mixture	P_2O_5 extracted per 100 grm. soil mixture	
	By 24 hours' shaking	By 48 hours' shaking
7	0 0363	0 0227
8	0 0257	0 0177
9	0 0231	0 0136
10	0 0194	0 0109
12	0·0109	0 0051
14	0·0088	0·0048

That is to say, the increased time of extraction leads to a decided reduction in the amount of P_2O_5 extracted, and this is not evidently due to adsorption phenomenon, but to an increased Ca-ion concentration in the solvent. The effect of the presence of $CaCO_3$ on the extraction of P_2O_5 is, therefore, mainly chemical in character.

Turning now to the figures in Table I for the available K_2O extracted, it is obvious that there is a falling off in the values obtained up to about 7 per cent. $CaCO_3$ present in the soil mixture, and beyond that the rate of reduction is hardly appreciable. This is shown in the following diagram.

DIAGRAM V.

Showing the effect of increasing proportions of $CaCO_3$ on the available K_2O extracted from Kalianpur soil by Dyer's method.



When the values for K_2O are carefully examined, it is evident that there is a gradual reduction in the amount extracted with the decreasing acidity of the solvent during the first stage up to about 7 per cent. $CaCO_3$ present, marking the point at which all the citric acid used is completely neutralized and afterwards the amount of K_2O extracted is practically constant with the almost neutral character of solvent produced.

Consequently, the presence of larger proportions of $CaCO_3$ than 7 per cent. has a much smaller effect on the K_2O values than is the case with P_2O_5, and the validity of Dyer's method applied to calcareous soils is not materially affected in its relation to available K_2O beyond the stage of 7 per cent. $CaCO_3$ present.

Finally, the following table shows that the extraction of the Kalianpur soil with solvents approximating in composition to those produced with varying proportions of $CaCO_3$ yields comparable values.

TABLE V.

Showing the amounts of P_2O_5 and K_2O extracted from Kalianpur soil with solvents corresponding to the phases produced with varying proportions of $CaCO_3$.

Solvent	Per cent. P_2O_5 extracted	Per cent. K_2O extracted	With corresponding phase by Dyer's method	
			Per cent. available P_2O_5	Per cent. available K_2O
Saturated solution of calcium citrate $+CO_2$	0·0069	0·0160	0·0363	0·0142
Saturated solution of calcium citrate+ calcium bicarbonate.	0·0012	0·0149	0·0025	0·0141

Hence, the conclusion emerges that the application of Dyer's method to calcareous soils results in the employment of solvents varying in composition according to the amount of $CaCO_3$ present.

Further, an extraction was made of the Pusa soil with 1 per cent. citric acid solution after neutralizing the $CaCO_3$ present with extra amounts of citric acid as was suggested by Dyer in the postscript of his paper (loc. cit.).

As 7·15 grm. of $CaCO_3$ are neutralized by 10 grm. of citric acid according to the equation—

$$\begin{array}{lll} C_1H_2.\,COOH & & \\ 2\,C_1.\,(OH).\,COOH,\,H_2O & +3\,CaCO_3 & =(C_6H_5O_7)_2Ca_3,\,4H_2O+3CO_2+H_2O \\ CH_2.COOH & 3\times100=300 & \\ 2\times210=420 & & \\ \text{Citric acid.} & \text{Calcium carbonate} & \text{Calcium citrate.} \end{array}$$

The 32·57 grm. of $CaCO_3$ present in 100 grm. of Pusa soil taken for the experiment will require 45·6 grm. of citric acid for complete neutralization, and consequently, while making the extraction, this amount of citric acid was dissolved in a litre of 1 per cent. citric acid solution. No allowance was, however, made for other basic substances, such as, Fe, Al, Mg, etc., present which might consume some of the citric acid for their solution. The results are shown in the following table and compared with those obtained with 1 per cent. citric acid solution alone.

TABLE VI.

Showing the amounts of P_2O_5 and K_2O extracted from Pusa soil by the original and the modified method of Dyer.

Solvent used	Per cent. P_2O_5 extracted	Per cent. K_2O extracted
1 per cent. citric acid solution alone (*original method*).	0·0003	0·0109
1 per cent. citric acid solution + sufficient citric acid to neutralize $CaCO_3$ present (*modified method*).	0·0154	0·0185

The value of P_2O_5 obtained with extra amount of citric acid as suggested by Dyer (loc. cit.) for calcareous soils, although considerably higher than Dyer's limiting figure of 0·01 per cent. P_2O_5, does not agree with the known manurial reactions of the Pusa soil and such other calcareous soils of Bihar. Hence, Dyer's contention breaks down in such cases as a discriminating agent.

Incidentally, it may be mentioned that Leather published the results of similar experiments a few years ago (loc. cit.) with a Pusa soil containing 38·63 per cent. $CaCO_3$. His figures for potash and phosphoric acid are unexpectedly lower than those I have obtained under similar experimental conditions. This is obviously due to the fact that he took 10 grm. of citric acid as being equivalent to 14·30 grm. of $CaCO_3$ instead of the correct amount of 7·15 grm. (see p. 46 of Leather's paper).

SUMMARY AND CONCLUSIONS.

1. Dyer's method breaks down as a means of estimating available phosphoric acid in calcareous soils. The application of 1 per cent. citric acid solvent in such cases is, in effect, an extraction with a series of dissimilar solutions, the composition of which depends mainly upon the $CaCO_3$ content of the soils.

2. In the case of available potash Dyer's method is at least unsuitable for those soils whose $CaCO_3$ content ranges from 1—7 per cent., beyond which, however, the extraction of potash is not materially affected by the presence of $CaCO_3$.

3. The suggestion made by Dyer for the use of an extra amount of citric acid to neutralize the $CaCO_3$ present in calcareous soils in addition to the usual 1 per cent. citric acid solution, produces results which are not correlated with the known manurial reactions of such soils.

4. This being the case, the values obtained by Dyer's method in the case of calcareous soils of varying $CaCO_3$ content cannot be correlated with one another, and far less so with non-calcareous soils. Consequently, the method must be looked upon with suspicion, until a rigorous correlation of the analytical data with definite manurial reactions of the soils under examination can be obtained.

PART II.

Extraction of Phosphoric Acid of Calcareous Soils with Salt Solutions.

In Part I it has been demonstrated that the presence of $CaCO_3$ interferes considerably with the estimation of available plant food in calcareous soils by Dyer's method (loc. cit.), and consequently renders the application of 1 per cent. citric acid solvent in such cases of dubious value. This being the case, the employment of such a solvent as is not appreciably affected by the presence of $CaCO_3$ is rendered necessary in order to secure a reliable indication of the fertility of these soils in relation to available plant food.

Most investigators who have proposed methods of determining available plant food in soils have employed an acid of weak concentration as the solvent. For example, dilute HCl, HNO_3 and CH_3. COOH of indefinite strength were proposed in the earliest papers on this subject by Liebig,[1] Deherain,[2] Vogel,[3] and Dugast[4]. 1 per cent. citric acid solution was proposed by Tollens[5], Ollech[6], Stutzer,[7] Thomson,[8] and Dyer[9], whereas Eggertz and Nilson[10], and Wiklund[11] used 2 per cent. HCl, *i.e.*, of about N/1·82 strength. The American Association of Official Agricultural Chemists prefers the use of fifth-normal HCl or HNO_3 for this purpose, whereas Moore[12] proposed N/200 HCl, Maxwell[13] 1 per cent aspartic acid, Schloesing, Jun.[14] dilute HNO_3 of various strengths, and Emmerling[15] 1 per cent. oxalic acid. On the other hand, Mitscherlich[16], Schloesing,[17] and Garlach[18] thought that the natural solvent of any theoretical interest is that of carbon dioxide only, which is excreted in the process of respiration by plants, and therefore proposed an aqueous solution of CO_2 as the solvent for estimating available plant food in soils.

A very few workers, however, have used alkaline or neutral salt solutions. For instance, Petermann[19] employed ammoniacal solution of ammonium citrate, Hoffmeister[20] ammoniacal solution of humic acid, Dugast[21] solutions of ammonium

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1 *Zeit. d. Landw. Ver.*, 1872.
2 *Ann. Agron*, 1881, **6**, 392-393; *ibid.*, **17**, 445-454.
3 *Bied. Centr.*, 1882, 852.
4 *Ann. Agron*, **9**, 470-478.
5 *Ber. d. deutsch. Chem. Gesell.*, 1880, **13**, 1267.
6 *Journ. f. Landw.*, 1882, **30**, 519.
7 *Chem. Ind.*, 1884, **7**, 37.
8 *Ibid.*, 1885.
9 *Trans. Chem. Soc.*, 1894, **65**, 115-167; and also *Phil. Trans.*, 1901, **194B**, 235 290.
10 *Bied. Centr.*, 1889, 664-668.
11 *Landw. Jahrb.*, 1892, **20**, 909-928.
12 *Journ. Amer. Chem. Soc.*, 1912, 791.
13 *Ibid.*, 1899, **21**, 4-15.
14 *Compt. rend.*, 1899, **128**, 1004.
15 *Bied. Centr.*, 1900, **29**, 75.
16 *Landw. Jahrb.*, 1907, **36**, 309-369.
17 *Compt. rend.*, 1900, **131**, 149.
18 *Landw. Versuchs. Stat.*, 1896, **46**, 201.
19 *Recherches der chimie et Physiologie*, 1898, **3**, 50.
20 *Landw. Versuchs. Stat.*, 1898, **50**, 363.
21 *Ann. Agron.*, 1884, **9**, 470-478.

oxalate, ammonium citrate, and also water, and Lechartier[1] 2 per cent. ammonium oxalate.

It has been generally recognized that some solvent weaker than strong mineral acid should be employed in the analysis of soils in order to obtain an indication of the proportion of available mineral plant food. Most of the suggestions made, however, have been arbitrary in the sense of not having any definite basis beyond the recognized necessity that the solvent should be a weak one.

It is obvious that the employment of ordinary acids will bring about a reaction with the calcium carbonate present in calcareous soils and introduce calcium-ions in the extracting liquid, which will tend to depress the concentration of P_2O_5 ions in the solution.

This being the case, it appeared desirable to make a study of the action of various salt solutions on the solubility of the phosphates of calcareous soils in order to find one which is not affected by varying amounts of $CaCO_3$. In this connection the study must also extend to the discovery of a solvent which is capable of dissolving such quantities of P_2O_5 as will not give rise to manipulative and analytical difficulties.

The same Kalianpur and Pusa soils as were used in Part I were also employed for this investigation.

Those salt solutions were chosen which probably would not be appreciably affected by the presence of $CaCO_3$.

Method of experiments. 100 grm. of various soil mixtures with $CaCO_3$ or Pusa soil were shaken with a litre of the solvent for 24 hours as in the case of Dyer's method in a mechanical shaker in end-over-end rotations in a room which was not subjected to sudden changes of temperature. After separating the extract by suction, the dissolved P_2O_5 was determined in the usual way by the molybdate ammonium method. In some cases the dissolved K_2O was determined by the platinic chloride method.

I. Extraction with 1 per cent. neutral ammonium citrate solution (N/8 strength).

TABLE I.

Showing the extraction of P_2O_5 from Kalianpur soil with 1 per cent. neutral ammonium citrate solution and the effect of $CaCO_3$ as such or in the form of Pusa soil on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture: Found	Grm. P_2O_5 per 100 grm. mixture: Calculated	Grm. K_2O per 100 grm. mixture: Found	Grm. K_2O per 100 grm. mixture: Calculated
	A.—*Kalianpur soil + $CaCO_3$*				
100	nil	0·0459	—	0·0359	—
95	5	0·0077	0·0436	0·0363	0·0341
90	10	0·0059	0·0413	0·0332	0·0323
85	15	0·0051	0·0390	0·0320	0·0305
80	20	0·0044	0·0367	0·0303	0·0287
75	25	0·0041	0·0344	0·0283	0·0269
70	30	0·0038	0·0321	0·0269	0·0251

[1] *Compt. rend.*, 1884, **98**, 1058-1061.

TABLE I—*concld.*

Grm. Kalianpur soil taken	Grm. Pusa soil added	Grm. P_2O_5 per 100 grm. mixture		Grm. K_2O per 100 grm. mixture	
		Found	Calculated	Found	Calculated
		B. *Kalianpur soil+Pusa soil*			
100	nil	0·0459	—	0·0359	—
95	5	0·0048	0·0436	0·0356	0·0349
90	10	0·0037	0·0416	0·0336	0·0338
85	15	0·0032	0·0391	0·0308	0·0327
80	20	0·0037	0·0369	0·0306	0·0317
75	25	0·0035	0·0346	0·0303	0·0306
70	30	0·0023	0·0324	0·0294	0·0295
nil	100	0·00086	0·00086	0·01467	0·01467

The extracts obtained were all brown in appearance, showing that an appreciable amount of organic matter was dissolved out. It is obvious that the presence of $CaCO_3$ in any form has depressed the solubility of the soil phosphates. Similar results were obtained by Harrison and Das[1], who found that $CaCO_3$ added to a saturated solution of dicalcic phosphate in 1 per cent. neutral ammonium citrate rendered insoluble some of the P_2O_5 from the solution under similar conditions. Further, it is evident that the effect of adding Pusa soil to the mixture on the extraction of P_2O_5 is much more depressing than pure $CaCO_3$. In the case of the extraction with an acid solvent such as the 1 per cent. citric acid solution the effect was just the reverse. Here, in the case of mixtures with Pusa soil evidently other factors come into play which do not operate in the case of the mixtures of Kalianpur soil with $CaCO_3$ and which bring about a greater reduction in the amount of P_2O_5 content. On the other hand, the effect on the K_2O extracted from the several mixtures is comparatively small, and consequently its estimation was not undertaken in the experiments which follow.

II. Extraction with a saturated solution of calcium citrate.

Table II.

Showing the extraction of P_2O_5 from Kalianpur soil with a saturated solution of calcium citrate and the effect of $CaCO_3$ as such or in the form of Pusa soil on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
A. Kalianpur soil+$CaCO_3$			
100	nil	0·00032	
95	5	0·00027	0·00030
90	10	0·00025	0·00029
85	15	0·00030	0·00027
80	20	0·00026	0·00026
75	25	0·00019	0·00024
70	30	0·00017	0.00022
B. Kalianpur soil + Pusa soil	Grm. Pusa soil added		
100	nil	0·00032	—
95	5	0·00033	0·00032
90	10	0·00030	0·00032
80	20	0·00025	0·00031
70	30	0·00019	0·00031
60	40	0.00017	0·00030
nil	100	0·00028	0·00028

All the extracts were colourless, showing the absence of organic matter from the solution. The effect of either $CaCO_3$ as such or in the form of Pusa soil on the extraction of P_2O_5 appears much less than in the case of 1 per cent. neutral ammonium citrate solution. It is to be noted, however, that the amount of P_2O_5 extracted from every soil mixture is so small as to give rise to great manipulative difficulties in its estimation by the standard ammonium molybdate method, and, therefore, likely to introduce large experimental errors. Consequently, it would not be desirable to draw any conclusion from such data unless a more reliable method for the estimation of P_2O_5 in minute quantities is available.

III. Extraction with a saturated solution of calcium citrate and calicum bicarbonate.

Table III.

Showing the extraction of P_2O_5 from Kalianpur soil with a saturated solution of calcium citrate and calcium bicarbonate and the effect of $CaCO_3$ as such or in the form of Pusa soil on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
	A. *Kalianpur soil + $CaCO_3$*		
100	nil	0·00122	—
95	5	0·00039	0·00116
90	10	0·00039	0·00110
85	15	0·00028	0·00104
80	20	0·00024	0·00098
75	25	0·00026	0·00092
70	30	0·00024	0·00085
	B. *Kalianpur soil + Pusa soil*		
	Grm. Pusa soil added		
100	nil	0·00122	—
95	5	0·00056	0·00118
90	10	0·00045	0·00114
80	20	0·00034	0·00107
70	30	0·00024	0·00099
60	40	0·00019	0·00092
nil	100	0·00046	0·00046

All the extracts were colourless, showing the absence of organic matter from the solution. It is evident that the presence of both $CaCO_3$ and Pusa soil has depressed the solubility of the soil phosphates, but the effect of Pusa soil is more pronounced than that of $CaCO_3$ as shown in the case of 1 per cent. neutral ammonium citrate solution.

IV. Extraction with 1 per cent. Na_2SO_4 solution (about N/7 strength).

Table IV.

Showing the extraction of P_2O_5 from Kalianpur soil with 1 per cent. Na_2SO_4 solution and the effect of $CaCO_3$ on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
100	nil	0·0014	--
95	5	0·0012	0·00133
90	10	0·0011	0·00126
85	15	0·0008	0·00119
80	20	0·0007	0·00105
75	25	0·0006	0·00105

As the extraction of Pusa soil with 1 per cent. Na_2SO_4 solution gave only 0·00032 per cent. P_2O_5, the study of its action was not considered necessary.

All the extracts were colourless. The amount of P_2O_5 extracted in some of the mixtures is so small as to have no practical value. The addition of $CaCO_3$ has, however, interfered with the extraction of P_2O_5 to a certain extent.

V. Extraction with 1 per cent. $(NH_4)_2 SO_4$ solution (about N/7 strength).

When the $(NH_4)_2SO_4$ solution, which gives acid reaction owing to hydrolysis, is shaken with $CaCO_3$, the resultant solution is alkaline to litmus owing probably to the production of $(NH_4)_2 CO_3$ according to the following equation--

$$(NH_4)_2SO_4 + CaCO_3 = CaSO_4 + (NH_4)_2CO_3.$$

The experimental results of the extraction of P_2O_5 are given in the following table.

Table V.

Showing the extraction of P_2O_5 from Kalianpur soil with 1 per cent. $(NH_4)_2SO_4$ solution and the effect of $CaCO_3$ on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 per 100 grm. mixture	
		Found	Calculated
100	nil	0·0015	—
95	5	0·0009	0·00143
90	10	0·0008	0·00135
85	15	0·0006	0·00128
80	20	0·0004	0·00120
75	25	0·0006	0·00113

The extracts were all colourless and slightly alkaline in reaction. The effect of $CaCO_3$ on the amount of P_2O_5 extracted is very pronounced.

VI. Extraction with 1 per cent. $(NH_4)_2CO_3$ solution (about N/5 strength).

Table VI.

Showing the extraction of P_2O_5 from Kalianpur soil with 1 per cent. $(NH_4)_2CO_3$ solution and the effect of $CaCO_3$ as such or in the form of Pusa soil on it.

Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm P_2O_5 per 100 grm. mixture	
		Found	Calculated
	A. *Kalianpur soil + $CaCO_3$*		
100	nil	0·0032	—
95	5	0·0050	0 00304
90	10	0 0057	0 00288
85	15	0·0062	0.00272
80	20	0·0063	0·00256
75	25	0·0064	0·00240
	B. *Kalianpur soil + Pusa soil* Grm. Pusa soil added		
100	nil	0·0032	—
95	5	0·0035	0·00308
90	10	0·0035	0·00296
80	20	0·0032	0·00273
70	30	0·0029	0·00249
60	40	0·0026	0·00226
nil	100	0·00084	0 00084

The extracts were all brownish, showing the presence of a considerable amount of humus in the solution. As the humus contains an appreciable proportion of P_2O_5, the results obtained are very interesting. The presence of $CaCO_3$ here does not reduce the amount of P_2O_5 extracted as in the previous cases. On the other hand, not being affected by the $(NH_4)_2CO_3$ solution it becomes an inert substance directly increasing the ratio of the solvent to the soil. Thus, with increasing amounts $CaCO_3$ in the soil mixtures, the solvent extracts more and more humus and consequently increasing proportions of P_2O_5, which is made evident from the results obtained.

On the other hand, the presence of Pusa soil does not appear to affect the extraction of P_2O_5 appreciably, as it consists not only of $CaCO_3$ as in the former case, but also other constituents of soil which are evidently acted on by the $(NH_4)_2CO_3$ solvent. The latter, being alkaline in reaction, is capable of extracting humus from Pusa soil as will be shown later on and it is well known that humus retains P_2O_5 with it. For

the present, however, it may be taken that all these phenomena play an important rôle on the results obtained and do not exert a depressing influence on the amount of P_2O_5 extracted. Thus, Pusa soil present in these soil mixtures being itself acted upon by the solvent employed cannot contribute towards incremental extraction of humus and P_2O_5 as the presence of pure $CaCO_3$ did in the case of its mixtures with Kalianpur soil.

Lastly, a few experiments were carried out in order to determine the amount of humus extracted from the soils used in this investigation, and also the proportion of P_2O_5 present in the same.

Ten or twenty grammes of each soil were treated directly with 500 c.c. of 4 per cent. ammonia solution in the cold and allowed to stand overnight. Then in an aliquot portion of the supernatant liquid humus was determined and in another portion P_2O_5 estimated in the usual manner. The results are shown in the following table.

TABLE VII.

Showing the amounts of humus and P_2O_5 in the humus extracted from Kalianpur and Pusa soils with 4 per cent. ammonia solution.

Substance	Per cent. humus	Grm. P_2O_5 in per cent. humus	Per cent. P_2O_5 in humus
Kalianpur soil	0 23	0·0115	5 00
Pusa soil	0·38	0·0022	0·58

Pusa soil contains 65 per cent. more humus than Kalianpur soil, but the humus of the latter is about 9 times richer in P_2O_5 content than that of the former.

Thus, although the presence of $CaCO_3$ does not directly interfere with the extraction of P_2O_5 by 1 per cent. $(NH_4)_2CO_3$ solution, it indirectly affects the extraction of P_2O_5 favourably as shown above. A similar effect, however, cannot be expected from the mixture with Pusa soil which takes part in the reaction involved, and this has been found to be the case as shown in Table VI (B) above.

In conclusion, it is believed that some alkaline solvent, while extracting appreciable amounts of P_2O_5 and at the same time not being appreciably affected by the presence of $CaCO_3$, will be found suitable for the estimation of available P_2O_5 in calcareous soils. This investigation will be dealt with in Part III of this Memoir.

SUMMARY.

With a view to find out a suitable solvent for the estimation of available phosphoric acid in calcareous soils, several salt solutions, such as, 1 per cent. neutral

ammonium citrate, saturated solution of calcium citrate, saturated solution of calcium citrate and calcium bicarbonate together, 1 per cent. Na_2SO_4, 1 per cent. $(NH_4)_2SO_4$ and 1 per cent. $(NH_4)_2CO_3$ solutions were employed in the extraction of a non-calcareous Kalianpur soil mixed with varying proportions of $CaCO_3$ and the calcareous Pusa soil. It was found that in most cases the presence of $CaCO_3$ in any form reduced the amount of P_2O_5 extracted. An exception was noticed in the case of 1 per cent. $(NH_4)_2CO_3$ solution when the effect of the $CaCO_3$ was an indirect one in that its increasing proportion in the soil mixtures increased the proportion of the solvent to the soil, and, consequently, the solvent, which is alkaline in reaction, extracted more and more humus and increasing amounts of P_2O_5 from the soil mixtures.

It was thought probable that some alkaline solvent, while extracting appreciable amounts of P_2O_5, would be found suitable for the estimation of available P_2O_5 in calcareous soils, as increasing proportions of $CaCO_3$ did not lead to a reduction in the amount of P_2O_5 extracted.

PART III.

Potassium Carbonate Method for Estimation of Available Phosphoric Acid of Highly Calcareous Soils.

It has been demonstrated in the earlier portions of this Memoir that the employment of acid solvents is inapplicable to the estimation of available phosphoric acid in calcareous soils and that calcium carbonate exerts a depressing influence on extraction by solutions of a number of salts. The investigations, however, indicated the possibility that some alkaline solvent would extract appreciable amounts of phosphoric acid which probably would be found of value in giving some criterion for the differentiation of the manurial requirements of soils of this type.

Ammonium hydroxide solutions extract humus and the phosphoric acid combined with it, from soils, and Olson[1] has shown that such solutions can be employed to differentiate between the mono-, di-, and tri-calcium phosphates not only in the presence of each other, but also as they exist in fertilizers, animal and plant tissues, soils, etc. In a previous paper,[2] the author has shown that in calcareous soils there is a very rapid reversion of mono- into di-calcic phosphate and that the latter only very slowly reverts into the tri-calcic form. On this basis, therefore, there would appear to be a possibility of employing ammonia solutions for the manurial differentiation of such soils, and a number of preliminary experiments were instituted to test this point.

In the first instance it was thought desirable to see whether or not varying proportions of soil to a fixed volume of solvent had any effect on the percentage of P_2O_5 extracted. Quantities of Kalianpur soil varying from 20 to 100 grm. were therefore extracted with 500 c.c. of 4 per cent. ammonia solution in the cold by shaking together for two hours and then allowing the mixture to stand overnight. The clear solution was separated by suction through a filter and the dissolved P_2O_5 estimated in the usual manner. The results are set forth in the following table.

TABLE I.

Showing the results of P_2O_5 extractions from varying amounts of Kalianpur soil with a constant volume of 4 per cent. ammonia solution.

Grm. Kalianpur soil taken	Volume of 4 per cent. ammonia solution added	Per cent. P_2O_5 extracted
20	500 c.c.	0·00098
30	,,	0·00098
40	,,	0·00098
50	,,	0·00118
100	,,	0·00101

[1] *Washington Agri. Exp. Sta. Bull.* 116, 1914.
[2] Harrison and Das. *Mem. Dept. Agri. India, Chem. Ser.*, Vol. V, No. 9, 1921.

Thus it is shown that, under very wide variations between the weight of soil taken and the volume of solvent used, the percentage of P_2O_5 extracted remains practically constant.

The next step was to determine the effect of the presence of calcium carbonate or Pusa soil on the amount of P_2O_5 extracted from mixtures. Mixtures of varying composition were made and extracted for six hours in a shaking machine with a 4 per cent. ammonia solution. After standing overnight the solution was separated by filtration and the P_2O_5 in it estimated. The results are given in the following table.

TABLE II.

Showing the effect of precipitated $CaCO_3$ on the extraction of P_2O_5 from Kalianpur soil with 4 per cent. ammonia solution.

Per cent. $CaCO_3$ in soil mixture	Grm. Kalianpur soil taken	Grm. $CaCO_3$ added	Grm. P_2O_5 extractable in soil mixture (*calculated*)	Grm. P_2O_5 extracted in soil mixture (*found*)	Difference
nil	300	nil	—	0·00229	—
5	285	15	0·00216	0·00144	—0·00072
10	270	30	0·00205	0·00124	—0·00081
20	240	60	0·00182	0·00083	—0·00099
30	210	90	0·00160	0·00056	—0·00104
40	180	120	0·00137	0·00039	—0·00098
80	60	240	0·00046	0·00016	—0·00030
100	nil	200	nil	nil	—

TABLE III.

Showing the effect of Pusa soil on the extraction of P_2O_5 from Kalianpur soil with 4 per cent. ammonia solution.

Per cent. Pusa soil in soil mixture	Grm. Kalianpur soil taken	Grm. Pusa soil added	Grm. P_2O_5 extractable in soil mixture (*calculated*)	Grm. P_2O_5 extracted in soil mixture (*found*)	Difference
nil	300	nil	—	0·00229	—
20	240	60	0·00209	0·00201	—0·00008
40	180	120	0·00191	0·00167	—0·00024
60	120	180	0·00172	0·00159	—0·00013
80	60	240	0·00154	0·00142	—0·00012
100	nil	300	0·00135	0·00135	—

These results show distinctly that the presence of $CaCO_3$ decreases the amount of P_2O_5 which is extracted from its mixture, but that this effect is comparatively small in mixtures with Pusa soil. This difference possibly may be due to the particles of $CaCO_3$ in the Pusa soil being partially protected by other soil constituents, and if this is the case, then by extracting increasing proportions of Pusa soil with the same volume of 4 per cent. ammonia solution and thus increasing the amounts of active $CaCO_3$ present, the percentage of P_2O_5 extracted should show a depression. Experiments on these lines were instituted and the results are given in the following table.

TABLE IV.

Showing the results of P_2O_5 extractions from varying amounts of Pusa soil with a constant volume of 4 per cent. ammonia solution.

Ratio of grm. Pusa soil : 500 c.c. 4 per cent. ammonia solution	Grm. Pusa soil actually taken	c. c. 4 per cent. ammonia solution actually used	Per cent. P_2O_5 extracted
20	120	3,000	0·00075
30	135	2,250	0·00067
40	180	2,250	0·00056
60	180	1,500	0 00053
80	240	1,500	0·00050
100	300	1,500	0·00045

It is evident that there is a decrease in the proportion of P_2O_5 extracted as the proportion of soil increases, a result diametrically opposed to that obtained from the Kalianpur soil, and it may be concluded that ammonia extraction is susceptible to the influence of $CaCO_3$ and therefore inapplicable to calcareous soils.

A reference to the experiments detailed in Part II shows that the presence of $CaCO_3$ had comparatively little effect on the P_2O_5 extracted by a 1 per cent. ammonium carbonate solution. It seemed desirable to use a stronger solution of ammonium carbonate and to compare its action with those of sodium and potassium carbonates. The results are given in the following table, the amount of soil and the volume of alkaline carbonate solution taken being 300 grm. and 1500 c.c. respectively.

TABLE V.

Showing the results of P_2O_5 extractions from Kalianpur and Pusa soils with approximately N/2 alkaline carbonate solutions.

N/2 solution used	Per cent. P_2O_5 from Kalianpur soil	Per cent. P_2O_5 from Pusa soil
2·85 per cent. $(NH_4)_2CO_3$	0·00458	0·00143
2·65 per cent. Na_2CO_3	0·00428	0·00249
3·45 per cent. K_2CO_3	0·00473	0·00271

It is found that in the case of the Kalianpur soil which is practically devoid of lime, the amounts of P_2O_5 extracted are practically the same with the three solvents tried, whereas in the case of the highly calcareous Pusa soil the amount of P_2O_5 extracted by the $(NH_4)_2CO_3$ solution is about half of what has been obtained by the rest of the solvents. The reason of this probably lies in the fact that $(NH_4)_2CO_3$ is a much weaker base than the other two and is unstable, especially in the presence of $CaCO_3$ which is a constituent of the soil itself. Further attempts with this solvent were therefore not made. Of the other two solvents, K_2CO_3 extracted a little more P_2O_5 both from Kalianpur and Pusa soils than Na_2CO_3. Potassium carbonate was therefore selected for further investigation, and extractions of Pusa soil with solutions of various strengths over different periods of time were carried out. 75 grm. of soil and 750 c.c. of the solvent were used in the following experiments and the results are set forth in the following table.

TABLE VI.

Showing the results of P_2O_5 extractions from Pusa soil with K_2CO_3 solution of various strengths over different periods of time.

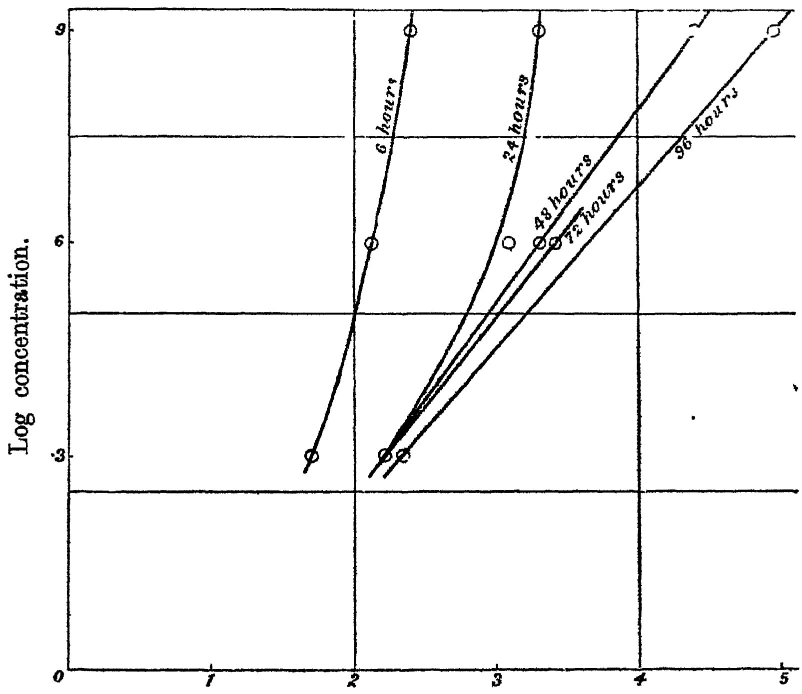
Time of shaking in hours	WITH ½ PER CENT. K_2CO_3 SOLUTION	WITH 1 PER CENT. K_2CO_3 SOLUTION	WITH 2 PER CENT. K_2CO_3 SOLUTION
	Per cent. P_2O_5 extracted	Per cent. P_2O_5 extracted	Per cent. P_2O_5 extracted
6	·00170	0·00214	0·00239
8	—	0·00221	—
24	0·00221	0·00309	0·00328
48	0·00221	0 00334	0·00441
72	0·00221	0 00340	—
96	0·00233	—	0·00498
120	—	0·00359	—

It is evident that the greater the concentration of K_2CO_3 solution used, the larger were the quantities of P_2O_5 extracted, and that the effect of time on the extraction of P_2O_5 is not much pronounced beyond 24 hours' shaking except in the case of 2 per cent. K_2CO_3 solution. On the other hand, the variation in the proportions of P_2O_5 extracted on 24 hours' shaking is much less pronounced than on longer periods of shaking. Further, 1 per cent. K_2CO_3 solution is capable of extracting an appreciable amount of P_2O_5 with 24 hours' shaking and this amount remains practically constant with longer times of shaking. Shaking with 1 per cent. K_2CO_3 solvent for 24 hours was therefore fixed as a standard method of procedure for the estimation of available phosphoric acid in calcareous soils. The fixing of the above standards is further confirmed by the following considerations.

The relationship between the amounts of P_2O_5 (P) extracted on shaking different lengths of time and the corresponding concentration (C) of K_2CO_3 solutions used turns out to be a simple semi-logarithmic one, as is shown by plotting the values of P against log C, when the curves produced are approximately straight lines. The following diagram demonstrates this, where concentrations are taken as 2, 4 and 8 respectively in the place of $\frac{1}{2}$, 1 and 2 per cent. K_2CO_3 for the sake of drawing the curves.

DIAGRAM I.

Showing the curves produced on plotting milligrams P_2O_5 extracted from Pusa soil against the logarithms of corresponding concentrations of K_2CO_3 solutions.



The relationship may thus be expressed by the general formula—

$$P = a + b \log C,$$

where $P =$ mg. P_2O_5 extracted,

$C =$ concentration of K_2CO_3 solution used,

and a and b are constants.

That is to say, the extraction of P_2O_5 from Pusa soil follows the law of mass action, the proportion of P_2O_5 extracted at any time being a function of the total

amount of P_2O_5 and depending upon the concentration of K_2CO_3 solution used. It is also evident from the curve that there is less variation in the amounts of P_2O_5 extracted with 24 hours' shaking, which has been adopted as the standard.

To find out the theoretical considerations underlying the action of K_2CO_3 solvent on the phosphates of calcareous soils, some experiments were next undertaken.

Extracting a sample of dicalcic phosphate with 1 per cent. K_2CO_3 solution *in the cold* yielded results which are set forth in the following table.

TABLE VII.

Showing the results of P_2O_5 extractions from dicalcic phosphate on being shaken for different periods of time.

Time of shaking in hours	Grm. dicalcic phosphate taken	1 per cent. K_2CO_3 solution added	Grm. P_2O_5 in solution after shaking	Per cent action
24	0·5	100 c. c.	0·0318	46·7 } mean= 49 6
24	1·0	,,	0·0697	50·7
24	2·0	,,	0·1411	51·4
48	1·0	,,	0·0939	68·2
96	1·0	,,	0·1292	93·9

The reaction between dicalcic phosphate and K_2CO_3 solution is thus seen to be a progressive one depending upon the time of shaking, the extraction evidently proceeding to completion after a little longer time than 96 hours. The reaction which takes place is shown by the following equation :—

$3\ CaHPO_4, 2\ H_2O + K_2CO_3 = Ca_3\ (PO_4)_2 + K_2HPO_4 + CO_2 + 7\ H_2O.$

$3 \times 172 = 516.$ Potassium Tricalcium Potassium

Dicalcic phosphate. carbonate. phosphate. phosphate.

(P_2O_5 in solution=71).

From this it follows that 1 grm. of dicalcic phosphate will leave in solution 0·1376 grm. of P_2O_5 from potassium phosphate produced when the reaction is complete.

The above table also shows that 94 per cent. action took place according to the above relation *in the cold* on 96 hours' shaking. It was therefore thought possible that the velocity of reaction will be quicker *in a boiling solution* and the reaction will be complete within a shorter space of time.

To test this, 0·7408 grm. of dicalcic phosphate was boiled with 70 c.c. of 1 per cent. K_2CO_3 solution for about ten minutes. Then, after separating the extract by filtration, the dissolved P_2O_5 was determined as usual. The results are shown below.

P_2O_5 *found* in solution = 0·1014 grm.
,, *calculated* ,, = 0·1019 ,,

Difference= — 0·0005

Thus, the reaction between dicalcic phosphate and 1 per cent. K_2CO_3 solution takes place according to the equation given above, whether in the cold or in a boiling solution.

Evidently, the underlying principle of the action of 1 per cent. K_2CO_3 solvent on calcareous soils seems to be that a reaction takes place with any dicalcic or such other phosphates present in the soils in the production of insoluble tricalcium or other phosphates, and of soluble potassium phosphate. The amount of P_2O_5 found in the extract thus serves to be an approximate measure of the available phosphoric acid of calcareous soils.

To find out the suitable ratio of soil to the solvent used in the extractions of P_2O_5, a definite amount of soil was extracted with varying proportions of the solvent. In this case, the soil mixtures were shaken for six hours only and then the whole allowed to stand overnight, after which the extracts were examined for the dissolved P_2O_5 as usual. The results are shown in the following table.

TABLE VIII.

Showing the results of P_2O_5 extractions from Pusa soil with varying amounts of 1 per cent. K_2CO_3 solution.

Ratio of grm. soil : c. c. solvent	Grm. Pusa soil actually taken	c.c 1 per cent. K_2CO_3 solution actually added	Per cent. P_2O_5 extracted
1 : 5	300	1,500	0·00186
1 : 10	150	1,500	0·00290
1 : 15	50	750	0·00255

It is thus demonstrated that when the soil and the solvent were taken in the ratio of 1 : 10, the maximum amount of P_2O_5 was extracted under the conditions of the experiment. This ratio was therefore taken as the suitable standard, and has since been adopted in all subsequent experiments.

It was found by experience that slight variations of temperature did not materially affect the results obtained.

The following method for the estimation of available phosphoric acid of calcareous soils is therefore recommended :—

" The soil is sampled by passing through a sieve of 2 mm. meshes after drying it in the air ; 100 grm. of it with a litre of 1 per cent. K_2CO_3 solution, or a similar proportion of the soil and the solvent, should be shaken in the cold for 24 hours in end-over-end rotations in a mechanical shaker in a room which is not subjected to sudden changes of temperature. In the extract separated by suction, the P_2O_5 is determined by the ammonium molybdate method."

A precaution has, however, to be taken during the analysis that the K_2CO_3 remaining free in the extract should be first neutralized almost wholly with nitric acid and then with a little hydrochloric acid, as a result of which considerable amounts of potassium nitrate will be produced in the solution, which is an advantage in the granular precipitation of ammonium phosphomolybdate during subsequent operations. Otherwise, if hydrochloric acid is used instead for neutralization in the beginning, the excess of chloride produced will, as is well known, materially interfere with the estimation of P_2O_5 by the molybdate method[1].

In order to verify this method as well as to compare its advantages over the existing citric acid method, a large number of calcareous soils from Pusa experimental plots, of $CaCO_3$ content ranging from 30 to 40 per cent.. was taken for examination, the cropping and manurial history of these soils being accurately known.

The total P_2O_5 content of these soils did not vary to a considerable extent and the figures for available P_2O_5 determined by the citric acid method, which were almost uniformly lower than 0·0005 per cent., were rather erratic. On the other hand, the amounts extracted by 1 per cent. K_2CO_3 solution, which gave a wider variation from about 0·002 to 0·005 per cent. P_2O_5, showed indication of being significantly related to the cultural history of the plots. The results obtained are given in the following table.

Table IX.

Showing the comparable results of total P_2O_5 by citric acid as well as potassium carbonate methods, of calcareous soils of known cropping and manurial history.

Plot No.	Description of plots	Treatment	Per cent. total P_2O_5	Per cent. available P_2O_5: By citric acid method	Per cent. available P_2O_5: By potassium carbonate method	Ratio $\frac{K_2CO_3 \text{ soluble } P_2O_5}{\text{Total } P_2O_5}$
1 B.	Punjab Field	No manure	0·1082	0·00029	0·00227	0·021
8 B.	,,	Superphosphate	0·1051	0·00029	0 00290	0·028
7 B.	,,	K_2SO_4	0·1033	0·00022	0·00233	0·023
9 B.	,,	,, + Super	0·1031	0·00019	0·00328	0·032
19 D.	,,	Green manure+ Gypsum.	0·0966	0·00011	0·00239	0·025
15 D.	,,	,, +Monocalcic phosphate.	0·0959	0·00009	0 00277	0·029

[1] Hibbard, P. L. A study of the Pemberton-Kilgore Method for the determination of phosphoric acid. *Jour. Indus. and Engin. Chem.*, 5, Dec. 1913, 968.

TABLE IX—*concld.*

Plot No.	Description of plots	Treatment	Per cent. total P_2O_5	Per cent. available P_2O_5: By citric acid method	Per cent. available P_2O_5: By potassium carbonate method	Ratio $\frac{K_2CO_3 \text{ soluble } P_2O_5}{\text{Total } P_2O_5}$
1 . .	North Pangarbi Field.	No manure .	0·1023	0·00006	0·00309	0 030
3 . .	„ . .	Superphosphate .	0·1054	0·00016	0·00479	0 045
2 . .	„ . .	Green manure .	0 1023	0 00006	0·00271	0 026
4 . .	„ . .	„ + Super	0·1021	0 00006	0·00391	0 038
1 . .	Pot Culture House Field.	No manure .	0·1071	0 00028	0·00392	0 035
8 . .	„ . .	Superphosphate .	0·1110	0·00107	0·00435	0·039
7 . .	„ . .	$(NH_4)_2SO_4$.	0 0941	0 00020	0·00353	0·038
4 . .	„ . .	„ +Super .	0·1065	0·00020	0·00410	0·039
9 . .	„ . .	K_2SO_4 . .	0·0972	0·00011	0·00397	0·041
6 . .	„ . .	„ +Super .	0·1111	0·00095	0·00536	0·048

In another case, a plot No. 30 B in the Punjab Field, which had received a dressing of super several years ago and none since, gave 0·00378 per cent. P_2O_5 by K_2CO_3 extraction, the corresponding no manure plot No. 27 B giving only 0·00258 per cent. against 0·00043 per cent. and 0·00052 per cent. available P_2O_5 respectively by the citric acid method from these plots. More recently, a supered plot in the Chhoania Field gave 0·00517 per cent. P_2O_5 as against 0·00277 per cent. P_2O_5 by K_2CO_3 extraction for an unmanured plot in the same field.

Thus, in practically all cases examined, the method of extracting with 1 per cent. K_2CO_3 solvent has differentiated between manured and unmanured plots, and also between plots treated with phosphatic fertilizers and those treated with other fertilizers having no phosphates in them, whereas the citric acid method yields uneven and misleading values.

In order to see whether this new method can differentiate between patches of soil carrying an uneven growth of a crop in the same field, an examination was made of calcareous soils taken from a field showing very irregular growth in the crop, samples being taken from good portions for comparison with samples from bad portions. The results are set forth in the following table.

TABLE X.

Showing comparable results of total P_2O_5 and available P_2O_5 by citric acid as well as by potassium carbonate methods of calcareous soils from good and bad cropping.

Description of plots	Per cent. total P_2O_5	Per cent. available P_2O_5		Ratio $\frac{K_2CO_3 \text{ soluble } P_2O_5}{\text{Total } P_2O_5}$
		By citric acid method	By potassium carbonate method	
Good cropping soil, No 1	0·1004	0·00038	0·00340	0·034
,, ,, ,, ,, 2	0·1011	0·00017	0·00296	0·029
,, ,, ,, ,, 3	0·1023	0·00016	0·00328	0·032
,, ,, ,, ,, 4	0·0979	0·00016	0·00334	0·034
Bad cropping soil, No 1	0·0981	0·00038	0·00365	0·037
,, ,, ,, ,, 2	0·1014	0·00032	0·00246	0·025
,, ,, ,, ,, 3	0·0972	0·00022	0·00239	0·025
,, ,, ,, ,, 4	0·0936	0·00022	0·00208	0·022

Thus, in three cases out of four, the good soils yielded appreciably higher values than the bad soils when examined by the K_2CO_3 extraction process, whereas with the citric acid method the reverse was the case.

Moreover, the ratios $\frac{K_2CO_3 \text{ soluble } P_2O_5}{\text{Total } P_2O_5}$ in the above two tables indicate that the K_2CO_3 solvent extracts appreciable quantities of P_2O_5 giving rise to no manipulative difficulties in their estimation which are very often met with in the case of small amounts of P_2O_5 extracted by the citric acid method. It is also evident that the proportions of P_2O_5 extracted with K_2CO_3 solution are many times greater than those obtained with the Dyer's method. As a matter of fact, the K_2CO_3 solution, being an alkaline solvent, extracts humus from soils, with which is associated a comparatively large amount of P_2O_5, whereas citric acid is incapable of doing so. It has already been shown to be the case in Part II (*loc. cit.*) that an alkaline solvent can extract humus and P_2O_5 combined with it from soils[1]. Thus, the greater solvent power of K_2CO_3 solution for soil phosphates is clearly demonstrated.

Furthermore, preliminary experiments carried out by the author in this laboratory[2] have shown that phosphorus in organic combination is more efficacious and easily available to plants than inorganic phosphorus in soils. Thus, it may perhaps be maintained that K_2CO_3 solution, which extracts phosphorus both in organic and

[1] Table VII, Part II.
[2] *Sci. Rept., Agri. Res. Inst., Pusa, India,* 1923-24, 24-25.

inorganic combinations in soils, is a very suitable solvent for estimating soil phosphates, which will be available for the nutrition of plants.

The conclusion thus emerges that the potassium carbonate method is capable of measuring the probable fertility of highly calcareous soils in their relation to available phosphoric acid. Moreover, it is a decided improvement on the existing citric acid method in that it has the following advantages over the latter.

1. The potassium carbonate method is capable of giving an indication of the probable fertility of calcareous soils in their relation to available phosphoric acid, whereas the citric acid method altogether fails as a discriminating agent in such soils.
2. The potassium carbonate solution is not materially affected by the presence of calcium carbonate.
3. It extracts higher proportions of P_2O_5 from calcareous soils in both organic and inorganic combinations, which are easily estimable by the ammonium molybdate method, whereas citric acid solution extracts in the majority of cases very small amounts of P_2O_5 giving rise to great manipulative difficulties in their estimation.
4. The potassium carbonate extraction is not practically affected by the time of shaking, whereas in the citric acid method a reference to the experiments detailed in Part I (*loc. cit.*) will show that the amount of P_2O_5 extracted is considerably depressed by a longer time of shaking.
5. The reaction of the potassium carbonate solution with the soil phosphates follows a simpler course, being controlled by the law of mass action.

Further investigation is in progress to see if this new method can be applied to other types of soils with similar advantage.

Summary and Conclusions.

1. Ammonium hydroxide, being affected by the presence of calcium carbonate, extracts very small quantities of P_2O_5 from calcareous soils and cannot therefore be applied for measuring their fertility. Other alkalis are likely to behave in a similar way, and they were therefore not tried.

2. A solution of ammonium carbonate, although not affected by the presence of calcium carbonate, extracts smaller proportions of P_2O_5 from calcareous soils than do those of the other common alkali carbonates, even when strong solutions of approximately half-normal strengths are used.

3. Of Na_2CO_3 and K_2CO_3, the latter extracts more P_2O_5, and was therefore selected for the investigation.

4. It has been proved that 1 per cent. K_2CO_3 solution is capable of differentiating between manured and unmanured plots of known cropping and manurial history, and it thus gives an indication of the probable fertility of calcareous soils in their relation to available phosphoric acid.

5. An improved method has been recommended as a substitute for the existing Dyer's method for the estimation of available phosphoric acid of a highly calcareous soil in that the soil should be extracted with a 1 per cent. K_2CO_3 solution, the proportion of the soil to solvent being as 1: 10, on being shaken for 24 hours at the ordinary laboratory temperature and then the dissolved P_2O_5 in the extract estimated by the ammonium molybdate method.

On the other hand, the citric acid method altogether fails as a discriminating agent in such soils.

6. The reaction between 1 per cent. K_2CO_3 solution and the phosphates of calcareous soils obeys the law of mass action.

7. It has been established that the underlying principle of the action of 1 per cent. K_2CO_3 solution on calcareous soils is that (*a*) a reaction takes place with any dicalcic or such other phosphates present in the soils in the production of insoluble tricalcium or other phosphates, and of soluble potassium phosphate, and that (*b*) phosphorus in organic combination present in the humus of the soils is also dissolved.

8. The potassium carbonate method is a reliable one, and it has several advantages over the existing Dyer's citric acid method for estimating the available phosphoric acid when applied to highly calcareous soils.

Experiments are in progress to see if this new method can be successfully applied to other types of soils.

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Deterioration of Sugarcane during its storage by Windrowing

BY

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AGRICULTURAL RESEARCH INSTITUTE, PUSA

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DETERIORATION OF SUGARCANE DURING ITS STORAGE BY WINDROWING.

BY

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(Received for publication on 27th June, 1925.)

Part I. Factors responsible for the deterioration of sugarcane windrowed in the field. Possibility of its successful storage in Bihar.

The results of the experiments on windrowing sugarcane in the North-West Frontier Province carried out in 1917-18 and 1918-19[1] "clearly show that cane can safely be stored for a certain period, after which a rapid deterioration sets in." The factors responsible for this were supposed to be either biological and solely connected with the cane or to be seasonal ones.

As in the two seasons mentioned above, the periods for which canes were preserved in good condition varied considerably, and in one particular season, 1918-19, the deterioration of canes set in at the same time whether they were windrowed early or late, it was suggested that the determining factor was a seasonal one. It was, however, observed that "this factor, or factors, is not easy of determination unless observations are extended over a series of seasons."

It is, however, significant that in both the seasons the windrowed canes remained in good condition so long as no heavy rainfall was experienced, but immediately after a heavy shower of rain deterioration was noticeable in them. It was, therefore, observed that "the incidence of heavy rainfall is (possibly) the factor which determines the incidence of deterioration."

The enquiry of the factors responsible for the deterioration of windrowed cane was continued both in the field and in the laboratory at Pusa. Series of experiments were carried out and a method was successfully evolved for the storage of sugarcane in Bihar by eliminating the causes for its deterioration.

It may not be out of place to mention here that windrowing is the term which has been adopted by the sugar planters of Louisiana to describe their own method of preserving sugarcane from rapid deterioration after the leaves have been killed by frost.

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[1] Harrison, W. H., and Sanyal, P. B. Effect (of windrowing sugarcane in N.-W. F. P.) on the composition of sugarcane. *Mem. Dept. Agri. India, Chem. Series,* Vol. V, No. 10 (1920).

As practised at Peshawar and at Pusa, the operation consists of cutting the canes with *kodali* or *belchi* about 3 to 4 inches below the surface of the field and then laying them down unstripped in such a way that the stems of one set of canes are covered with the leaves of the tops of the other. The object of the whole operation is to cover the canes well with trash (cane leaves) which will prevent their rapid drying. A couple of dry nodes with roots at the bottom resist easy infection by fungus or bacteria from the surroundings and retard evaporation of moisture from the cut end. Experiments have shown that, if the cut is higher and there are facilities for loss of moisture by evaporation, the canes dry up rapidly and deteriorate.

Effect of windrowing in the field and shade at Pusa on the composition of Sugarcane.

An account of the experiments on windrowing of sugarcane carried out at Pusa during the three seasons 1920 to 1923 is given below.

In 1920-21, two lots of sugarcane, variety Sathi 131, were windrowed in the open, once in December and again in February, samples being drawn from them occasionally for analysis. There was no heavy rainfall during the months of December, January and February and the mean and maximum temperatures in shade did not exceed 19° C. and 27° C. respectively.

The results of the analyses of canes from the first lot (Table I) show that, under the above condition of temperature and with practically no rainfall till the end of January, the canes remained in quite a good condition for 51 days up to the beginning of February. A comparison of initial (18-12-20) and final (7-2-21) values show the same conclusions as were derived at Peshawar (1917-19), *viz.*, the total solids present in juice increased with the simultaneous decrease in the average weight of a cane showing that the canes have dried up to some extent. Increase in the sucrose content and the purity of juice and the formation of no additional amount of glucose during the whole period show that the *canes were preserved in perfectly good condition for 51 days.*

TABLE I.

Sathi 131 windrowed at Pusa in December, 1920.

Date of analysis	Days windrowed	Average weight of a cane	Per cent. juice	Purity of juice	In juice			Rainfall	
					Brix	Per cent. Sucrose	Per cent. Glucose	Inches	Date
		lb.							
18-12-20 . .	0	2·83	59·81	79·84	16·88	13 84	2·08	..	..
23-12-20 . .	5	2·85	58 07	79·34	17·23	13·67	2·59		
3-1-21 . .	16	2·80	57·57	77·14	17·06	13·16	2·59	Traces Do.	2-1-21 3-1-21
17-1-21 . .	30	2 28	55·79	78·40	17·76	13·92	2·33		
7-2-21 . .	51	2·52	63·46	82·00	18·32	15·02	1·98	0·51	22-1-21

TABLE II.

Sathi 131 windrowed at Pusa in February, 1921.

Date of analysis	Days windrowed	Average weight of a cane	Per cent. juice	Purity of juice	Brix	Per cent. Sucrose	Per cent. Glucose	Inches	Date
10-2-21 . .	0	3·07	64·93	87·94	18·45	16·22	1·01	..	..
28-2-21 . .	18	2·33	64·42	80·06	21·27	17·03	2·42		
16-3-21 . .	34	2·19	62·60	80·33	21·96	17·65	2·70	0·13 0·19 Traces	8-3-21 9-3-21 14-3-21
2-4-21 . .	51	1·67	55·76	66·31	27·13	17·99	6·42		
14-4-21 . .	63	2·05	57·53	65·24	25·06	16·35	6·43	Traces	9-4-21

The second lot of cane, windrowed on 10th February, showed a tendency towards deterioration from the very beginning (Table II). The rise in glucose per cent. in juice from 1·01 to 2·42 and the fall in the purity of juice from 87·94 to 80·06, as revealed from the analysis of 28th February, are indications of this deterioration which, in the absence of any rainfall, is perhaps to be attributed to the higher atmospheric temperature prevailing during the period, the maximum having risen to 32·3°C. and the mean to 22° C. A slight increase in sucrose is evidently due to the concentration of the juice as a result of the drying up of the cane, the average weight of which fell from 3·07 to 2·33 pounds.

Brix and glucose continued to increase (in juice) slowly till the next fortnight (analysis of 16th March). There was 0·32″ of rainfall in two days on the 8th and 9th of March, and this amount had very little effect on the canes. The deterioration of the cane in the next fortnight (analysis of 2nd April) was, however, considerable, the glucose figure rising to 6·42 and the purity of juice falling to 66·31 per cent. This is another instance of rapid deterioration of the windrowed cane without rainfall and probably this is due to the high atmospheric temperature, the maximum having risen to 41·4° C. and the mean to 30·1° C. within the heap of cane, those recorded in shade in air being 34·2° C. and 27·7° C. respectively.

The results of the season go to show that though it is possible, in the absence of any appreciable rainfall, to preserve canes by windrowing in the field at Pusa during the months of December and January, this is not so in the latter part of the season (February to April) when the canes in the field are exposed to high temperature of the sun in addition to occasional falls of rain.

Experiments on the windrowing of sugarcane under Pusa conditions were continued next year (1921-22) with the Maneria cane (a thin cane). A crop from a $\frac{1}{10}$th acre plot was windrowed in an open place on 23rd December, 1921, and again on 23rd January, 1922. Samples were drawn from them at intervals and analysed. Contrary to the experience of the previous year, there were falls of rain and the canes in both these instances got wetted from the beginning. Their deterioration was immediately and definitely established as will be seen from the figures in Tables III and IV.

Canes windrowed on 23rd December got wetted once on 24th December and again on 10th January. The results clearly bring out their highly deteriorated condition, the sucrose per cent. falling from 13·09 to 8·74 and glucose rising from 0·95 to 5·47 (Table III). The canes remained in almost the same deteriorated condition till 10th January, in spite of further occasional rainfalls. Analysis on 2nd March, however, shows that the canes dried up rapidly owing to the higher atmospheric temperature during the last three weeks the average weight of a cane falling from 1·11 to 0·71 lb. This had not only the effect of concentrating the juice, the Brix in which rose from 18·86 to 20·23, but in the absence of any further rainfall during the period is also probably responsible for the production of a much larger amount

of glucose (from 3·32 to 7·70 per cent.) or, in the other words, the enhanced deterioration of the canes.

Owing to the rainfall on the very day of windrowing and three times during the next fortnight the condition of the canes windrowed on 23rd January was found to be as bad as those windrowed in December from the very beginning (Table IV). This confirms the conclusion that *rainfall immediately deteriorates the windrowed canes.* It may be noted here that the canes of the Maneria variety being thin, were more easily affected by a small amount of rainfall than was the case with the thick cane Sathi 131.

TABLE III.

Maneria windrowed in the open on 23rd December, 1921.

Date of analysis	Days after windrowing	Average weight of a cane	Per cent. of juice expressed	Composition of juice			Rainfall	
				Brix	Per cent. Sucrose	Per cent. Glucose	Inches	Date
		lb.						
23-12-21	0	1·15	63·98	16·10	13·09	0·95	0·01 0·23	25-12-21 11-1-22
18-1-22	26	1·19	57·02	18·71	8·74	5·47	0·01 0·10	22-1-22 23-1-22
23-1-22	31	1·06	60·34	18·16	8·88	4·90	0·07 0·25 0·20	30-1-22 4-2-22 5-2-22
10-2-22	49	1·11	59·18	18·86	8·12	3·32	..	..
2-3-22	69	0·71	54·34	20·23	8·74	7·70	..	..

TABLE IV.

Maneria windrowed in the open on 23rd January, 1922.

Date of analysis	Days after windrowing	Average weight of a cane	Per cent. of juice expressed	Brix	Per cent. Sucrose	Per cent. Glucose	Inches	Date
23-1-22	0	1·14	62·99	17·15	14·43	0·66	0·10 0·07 0·25 0·20	23-1-22 30-1-22 4-2-22 5-2-22
6-2-22	14	1·15	60·33	18·82	10·12	5·80	..	..
22-2-22	30	1·28	57·81	19·70	9·22	6·62	..	..
3-3-22	39	0·82	56·96	19·28	10·62	5·16	..	..

All the experimental results obtained both at Pusa and at Peshawar have led to the conclusion that the period for which sugarcane can safely be stored by windrowing is determined by the incidence of rain and of high temperature of the atmosphere. Experiments were next carried out in 1923 on the storage of sugarcane by windrowing it both in the field and in shade in order to bring out clearly the effect of climatic variations.

A stand of cane Co. 213 from a $\frac{1}{32}$nd acre plot was lifted on 9th January, 1923, and divided into two portions. One portion was windrowed in the field, exposed to sun and rain, and the other was stored in shade on the same day.

On 1st February, the cane from another plot of an equal area was treated similarly. Analyses were made of these canes at intervals and the results are set forth in Tables V, VI, VII and VIII. Tables V and VII also show the rainfall during the period of storage of sugarcane.

A comparison of the results show that the canes stored under protection from rain and sun remained in excellent condition for more than a month, whereas those exposed to climatic variations rapidly deteriorated.

This year's work, therefore, confirms the conclusions arrived at in previous years and demonstrates the *possibility of storing sugarcane in Bihar by windrowing it in shade.*

TABLE V.

Co. 213 windrowed in the field on 9th January, 1923.

Date of analysis	Days after windrowing	Average weight of a cane	Composition of juice				Rainfall	
			Brix	Per cent. Sucrose	Per cent. Glucose	Purity	Inches	Date
		lb.						
9-1-23	0	1·56	17·64	15·09	0·84	85·57	..	..
16-1-23	7	1·70	18·69	15·25	1·66	81·58	{ 0·01 0·02	22-1-23 23-1-23
1-2-23	23	1·70	19·37	15·17	2·38	78·34	0·11	11-2-23
12-2-23	34	1·79	20·64	14·88	3·83	72·11	0·28	16-2-23
17-2-23	39	1·65	20·57	14·88	3·18	72·35	0·32	17-2-23
24-3-23	74	1·67	18·75	13·03	3·58	69·50	1·82	24-2-23

TABLE VI.

Co. 213 windrowed under shade on 9th January, 1923.

Date of analysis	Days after windrowing	Average weight of a cane	Brix	Per cent. Sucrose	Per cent. Glucose	Purity	Inches	Date
9-1-23	0	1·56	17·64	15·09	0·84	85·57	..	..
16-1-23	7	2·20	17·63	15·40	0·74	87·36	..	..
1-2-23	23	1·41	17·85	14·51	1·33	81·27	..	..
12-2-23	34	1·64	19·00	15·51	1·50	81·65	..	..
17-2-23	39	1·64	18·63	15·63	1·26	83·88	..	..
24-3-23 . .	74	1·43	20·37	15·37	2·50	75·47	..	..

TABLE VII.

Co. 213 windrowed in the field on 1st February, 1923.

Date of analysis	Days after windrowing	Average weight of a cane	Composition of juice				Rainfall	
			Brix	Per cent. Sucrose	Per cent. Glucose	Purity	Inches	Date
		lb.						
1-2-23	0	2·78	18·56	16·71	0·60	90·03	....	....
7-2-23*	6	2·32	18 64	15·56	1·69	83·46	0·11	11 2-23
12-2-23	11	2 09	19·29	15·69	3 31	81·34	0·28	16-2-23
17-2-23	16	1·98	19·29	15·18	2·11	78·72	0·32	17-2-23
24-3-23	51	2·17	20·67	14·60	4·21	70·64	1·82	24-2 23

TABLE VIII.

Co. 213 windrowed under shade on 1st February, 1923.

Date of analysis	Days after windrowing	Average weight of a cane	Brix	Per cent. Sucrose	Per cent. Glucose	Purity	Inches	Date
1-2-23	0	2·78	18·56	16·71	0·60	90 03	..	..
7-2-23	6	1·81	19·78	17·27	0·96	87·30	..	..
12-2-23	11	1·98	19·55	16 49	0·60	84·33	..	..
17-2-23	16	2·05	19·18	16·92	0·54	88·23	..	..
24-3-23	51	1·68	20·53	17·42	1·54	84·86	..	..

Influence of temperature on the composition of sugarcane.

It has already been shown that rainfall is one of the factors responsible for the deterioration of windrowed sugarcane. During the investigation, instances, however, were met with where considerable deterioration of cane had taken place without any appreciable rainfall. It was also noticed that the deterioration of windrowed cane was more vigorous in the months of March and April when the atmospheric temperature at Pusa was much higher than that in December, January and February (Tables I and II).

An enquiry was, therefore, undertaken to investigate how far the variation of temperature is responsible for the deterioration of cane.

With this object in view cane pieces, each consisting of one internode and two nodes at the ends, the latter being sealed with paraffin, were kept at different temperatures in the laboratory. The composition of these canes was determined initially and samples were again examined after three days' exposure to the following temperatures and the results stated in Table IX.

Table IX.

The effect of different temperatures on the composition of sugarcane.

Date	Temperature maintained	Days exposed	Per cent. Loss in weight	Composition of juice			Glucose ratio
				Brix	Per cent. Sucrose	Per cent. Glucose	
21-2-21	Fresh cane	0	..	19·68	17·82	0·79	4·41
24-2-21	20°-24° C.	3	0·90	19·26	17·91	0·41	2·31
4-3-21	Ditto	11	8·74	21·26	17·79	1·96	11·01
24-2-21	27°-31° C.	3	5·09	19·10	17·32	1·18	6·79
3-3-21	Ditto	11	17·30	21·31	13·45	5·75	42·77
24-2-21	47°-51° C.	3	16·9	22·68	19·50	1·83	9·38
4-3-21	Ditto	11	..	..	..	..	36·05

The results show that cane pieces remained in fairly good condition at 20°-24° C., while their deterioration was quite pronounced when they were exposed to 27°-31° C. It is important also to note that the higher the temperature was above 24° C., to which the canes were exposed, the more vigorous was the loss of moisture in them and the more rapid was their deterioration.

The experiment was repeated when the cane pieces were maintained for six days at about 20° C., 25° C., 30° C. and 40° C. when the following results were obtained.

TABLE X.

Effect of different temperatures on the composition of sugarcane.

Date of analysis	Description	Loss of moisture per cent.	COMPOSITION OF JUICE						Glucose ratio
			BRIX		PER CENT. SUCROSE		PER CENT. GLUCOSE		
				Allowing for drying (on fresh cane)		Allowing for drying (on fresh cane)		Allowing for drying (on fresh cane)	
16-3-21 . . .	Fresh cane . .	..	20·67	..	16·63	..	2·26	..	13·58
22-3-21 . . .	Cane kept at 20° C. for six days.	3·99	18·15	17·43	15·23	14·62	2·28	2·19	14·97
22-3-21 . . .	Cane kept at 25° C. for 6 days.	6·81	19·08	17·78	15·90	14·82	2·74	2·55	17·23
22-3-21 . . .	Cane kept at 30° C. for 6 days.	10·95	18·20	16·21	13·62	12·13	4·24	3·78	31·13
22-3-21 . . .	Cane kept at 40° C. for 6 days.	17·92	21·27	17·46	14·98	12·30	5·12	4·20	34·18

The above results conclusively prove that cane, when exposed to 25° C., begins to deteriorate rapidly. It thus follows that *a temperature above 25° C. is prejudicial to the storage of sugarcane.*

The above conclusion was confirmed by the condition of sugarcane windrowed in the field on 10th February, 1921 (Table II). The mean temperature in shade was 24·6° C. on 16th March, and it rose up to 30·4° C. on 2nd April. The condition of the canes was fairly good till 16th March when the mean temperature was below 25° C., but it was much worse on 2nd April when the mean temperature was far above 25°C.

It may here be mentioned that this factor could not affect the windrowed sugarcane in our experiments at Peshawar during the seasons 1917-18 and 1918-19, as the mean temperatures in shade till the middle of March for those two years were less than 66° F. or 19° C. The normal maximum of Peshawar till the end of March (average of 33 years) was 75° F. or 23·9° C.[1]

Summary and conclusions.

1. Rainfall is the principal factor in determining the period during which sugarcane can be stored in good condition by windrowing in the field.
2. A temperature above 25° C. is prejudicial to the storage of sugarcane.
3. In the absence of any appreciable amount of rainfall, though it is possible to preserve sugarcane by windrowing in the field in Bihar during the months of December and January, deterioration is apt to take place in the latter part of the season (February to April) when the temperature rises and there is a likelihood of occasional falls of rain.
4. It is, however, possible to preserve sugarcane in good condition in Bihar for more than a month by storing it *in shade* by eleminating the influence of sun and rain.

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[1] Brown, W. Robertson. Windrowing of Sugarcane in N.-W. F. P. *Mem. Dept. Agri. Ind., Chem. Ser.*, Vol. V, No. 10 (1920), p. 238.

Part II. Mechanism through which the inverting enzyme in windrowed sugarcane is brought into activity on rainfall and causes its deterioration.

In conjunction with the investigation of the factors, rainfall and high atmospheric temperature, that have been found to be responsible for the deterioration of windrowed sugarcane, a study was made regarding the nature of the enzyme inducing deterioration of windrowed sugarcane on which rain falls and also of the way in which it acts.

DETERIORATION OF CANE IS A FUNCTION OF THE ENZYME PRESENT IN IT.

That the deterioration of sugarcane takes place by the agents already present in cane such as the enzymes, and not by any extraneous bodies, such as bacteria from the air or the soil, has been established by the following experiments.

(1) A portion of cane was split into two halves. One half was analysed fresh and the other half left covered with paraffin for 11 days and then analysed with the following results.

TABLE XI.

The effect of covering split cane with paraffin for 11 days on its composition.

Date	Treatment	COMPOSITION OF JUICE		
		Brix	Per cent. Sucrose	Per cent. Glucose
23-12-19 .	Fresh half	17·38	12·11	3·11
3-1-20 .	Half covered with paraffin for 11 days .	14·44	9·96	2 25

Fall in the Brix and the sucrose per cent. in juice evidently shows the deterioration of the cane.

(2) A portion of cane was split as before and the two halves analysed, one half before and the other half after exposure to moist toluene vapour for 3 days. The results in Table XII show a positive deterioration of the cane left in toluene vapour.

TABLE XII.

The effect of moist toluene vapour on the composition of sugarcane.

Date	Treatment	Composition of juice		
		Brix	Per cent. Sucrose	Per cent. Glucose
19-12-19 .	Fresh half	19·65	15·14	2·72
22-12-19 .	Half exposed to toluene vapour for 3 days .	16 53	12·69	2 47

The fact that the deterioration of cane took place when it was covered with paraffin or was exposed to the vapour of a strong antiseptic like toluene shows that the agents responsible for the action are present in the cane itself and do not enter into it from outside sources.

It is significant that in both the cases the glucose figure did not show any increase though the sucrose decreased by more than two per cent. This is probably due to the consumption of the reducing sugars either by the cane tissue during their respiration under the influence of the oxidizing enzymes or by being used up for the development of new tissues during germination.

NATURE OF THE ENZYMES OCCURRING IN SUGARCANE.

On an enzymic survey of the cane the following were detected :—

(1) *Oxidases* were found in all parts of cane ; their concentration being the highest at the top portion and lowest at the bottom.

(2) *Invertase* was mostly detected in the nodes of mature cane and slightly in the top internodes.

(3) *Catalase* was found in the juice.

(4) Evidence of the presence of *Cytase* was also obtained in the nodes as the extract from the latter slightly disintegrated the potato slices.

LABORATORY DEMONSTRATION OF THE EFFECT OF SLOW DESICCATION AND SUBSEQUENT WETTING OF SUGARCANE ON ITS COMPOSITION.

It has been definitely shown in Part I that canes, on proper protection, can be preserved in excellent condition for a long time in dry atmosphere and that if they come in direct contact with water after desiccation, their immediate deterioration is the consequence.

Portions of cane, each with an internode and two nodes at the ends, open ends being sealed with paraffin to avoid rapid evaporation of moisture, were divided into three parts. The first part, after the separation of the nodes, was analysed fresh, and the other two parts were kept in a desiccator over sulphuric acid for some time. The second part was next analysed after exposure to dry atmosphere and the third part was dipped in water for a few hours and exposed to moist atmosphere overnight and analysed as the first and second parts. The experiment was repeated and the results given below.

TABLE XIII.

Effect of slow desiccation, and wetting after desiccation, on the composition of sugarcane.

Date of analysis		Description of treatment	Per cent loss of weight from fresh weight	Composition of juice		
				Brix	Per cent Sucrose	Per cent Glucose
Experiment I	10-2-20 . . .	Fresh cane . . .	..	19·93	16·56	1·25
	8-3-20 . . .	Cane after slow desiccation for 27 days.	12·12	21·03	18·52	0·80
	9-3-20 . . .	Do. wetted . .	10·89	20·62	17·89	0·77
Experiment II	16-11-20 . . .	Fresh cane . . .	..	14·51	9·12	3·94
	29-11-20 . . .	Cane after slow desiccation for 13 days.	11 66	16·31	12·69	2·76
	30-11-20 . . .	Do. wetted . . .	7·81	14 96	10·27	3 63

It is thus seen (1) that the enzyme activity, which causes the deterioration of cane, is effectively checked, but not destroyed, by the slow desiccation of the latter. During this period the cane loses a considerable amount of moisture.

(2) That on wetting the cane for a short time after its desiccation, an appreciable amount of moisture quickly enters into it, causing an immediate deterioration.

The part that water plays in inducing the enzymes to activity was next investigated. It has been shown that canes deteriorate by the action of enzymes present in them, and it has also been established that incidence of rain causes the deterioration of windrowed cane. In the last experiment it was demonstrated that a small amount of water entered the somewhat dry cane and deteriorated it immediately. It is, therefore, essential to find out the exact locality at which water enters into windrowed cane, and the following three experiments were carried out for the purpose.

For each experiment, nine windrowed canes were divided into three lots of three canes in each. The first lot was crushed and analysed before the experiment. The

surfaces at the nodes of the second lot and those at the internodes of the third lot were covered with paraffin. Both the lots were wetted in water and their composition ascertained on the next day. From the increase in weight, the amount of water that entered into them was found out in the second and third experiments From the results of the experiments stated in Table XIV it will be clearly seen that water entered the windrowed canes almost wholly through the nodes and immediately deteriorated them

Concentration of the enzyme invertase in different parts of fresh and windrowed cane.

Different parts of fresh mature sugarcane (Co. 213) were ground with sand in an iron mortar and the pulp squeezed through linen. 3 c.c. of the enzyme extract were added to 100 c. c. of sucrose solution and left with toluene for 24 hours. The glucose was estimated in the mixture before and after the experiment with the following results (Table XV.)

Description	Mean wt. of a cane	Wt. increased on wetting		In juice			Water entered on wetting
		From	To	Brix	Per cent. Sucrose	Per cent. Glucose	
	Kilos	Kilos	Kilos				Per cent.
Experiment I.							
3 ratoon canes windrowed for 30 days in shade	0·600	..	..	23·44	11·20	8·28	..
Do. Nodes waxed and covered with moist cloth	0·603	..	..	22·63	10·72	8·31	..
Do. Internodes waxed and covered with moist cloth.	0·593	..	..	24·17	10·18	11·33	..
Experiment II.							
3 canes windrowed for 14 days in shade (Co. 213)	0·887	..	..	20·75	17·14	1·53	..
Do. Nodes waxed and wetted for 4 hours	0·823	2·48	2·495	20·26	16·93	1·20	0·61
Do. Internodes waxed and wetted for 4 hours	0·840	2·58	2·64	19·78	16·51	1·89	2·38
Experiment. III.							
3 canes (Co. 213) windrowed for 33 days in shade.	0·583	..	..	23·87	19·03	2·53	..
Do. Nodes waxed and wetted for 16 hours	0·816	2·48	2·54	22·47	19·06	1·76	2·45
Do. Internodes waxed and wetted for 16 hours	0·850	2·62	2·765	20·27	15·28	2·71	5·50

TABLE XV.

Concentration of the enzyme invertase in different parts of fresh mature cane.

Parts of cane	Glucose formed in 24 hours with 3 c. c juice	Order of invertase concentration
	gm.	
Nodes of top portion	0·042	(1)
„ middle portion	0·025	(3)
„ bottom portion	0·034	(2)
Internodes of top portion	0·022	(4)
„ middle portion	0·008	(5)
„ bottom portion	nil.	(6)

Invertase concentration is thus the highest at the top nodes and practically nil in the middle and bottom internodes. The enzyme concentration in the bottom node is more than that in the middle but less than that in the top nodes. Some of the invertase appears to remain diffused in the top internodes, and it is probably for this reason that we find the juice in this part to be less sweet.

Enzyme extracts were then prepared from the canes windrowed in the shade for about two months and tested for their invertase activity with the following results.

TABLE XVI.

Concentration of the enzyme invertase in the nodes of the different parts of windrowed cane.

Nodes from the parts of the windrowed cane	Glucose formed in 47 hours with 3 c. c juice	Order of invertase concentration
	gm.	
Top	0·142	(2)
Middle	0·087	(3)
Bottom	0·410	(1)

In the bottom node, therefore, the invertase concentration was found to be the highest in the case of windrowed canes. Next in order was in the top nodes and the concentration of the enzyme was the least in the middle nodes.

TRANSLOCATION OF THE ENZYME INVERTASE FROM THE NODES TO THE INTERNODES WITH THE PASSAGE OF WATER INTO THE WINDROWED CANES.

The windrowed canes were very dry as was evident from the hollow pith. It appeared from the following experiment that, when any part of these canes came in contact with water, the latter was at once drawn to all other parts of the cane. Results of the analysis of the different parts of the windrowed cane before and after they came in contact with water revealed the manner in which the enzyme invertase diffused in them and caused their deterioration. Nine windrowed canes of almost the same size and weight were selected and treated as follows :—

(1) Three of these were divided each into three parts. The three top, three middle and the three bottom portions so obtained were analysed at once.
(2) Three canes were hung upside down with their tops dipping in 6″ of water in a jar for a day. They were then divided into three portions (top, middle and bottom) and analysed.
(3) Three canes were dipped vertically in water up to 6″ height at the bottom for a day and then divided as in (1) and (2) and analysed.

The results are set forth in Table XVII.

TABLE XVII.

Effect of quick passage of water in bringing about the translocation of the inverting enzyme in windrowed cane.

Composition		(1) Initial analysis of windrowed cane	(2) Analysis of windrowed canes dipped invertedly at the top in water for 23 hours	(3) Analysis of windrowed canes dipped at the bottom in water for 23 hours	Order of deterioration
Top portion	Per cent. juice expressed	55·81	52·30	51·78	(2)
	Brix in juice	18·68	19·65	18·52	
	Per cent. sucrose in juice	15·81	14·83	13·67	
	Per cent. glucose in juice	0·99	2·32	2·45	
	Purity of juice	84·62	75·49	73·79	
Middle portion	Per cent. juice expressed	56·73	54·50	56·02	(3)
	Brix in juice	19·43	20·13	19·65	
	Per cent. sucrose in juice	17·65	17·81	17·05	
	Per cent. glucose in juice	0·48	0·93	1·08	
	Purity of juice	90·82	88·50	86·78	
Bottom portion	Per cent. juice expressed	59·09	56·13	56·15	(1)
	Brix in juice	20·21	19·53	19·11	
	Per cent. sucrose in juice	18·77	15·54	14·60	
	Per cent. glucose in juice	0·32	1·85	2·02	
	Purity of juice	92·87	79·57	78·19	

It will be seen from the above results that the middle portions, whether the canes were dipped upside down with the tops in contact with water or they were dipped at the bottom in their natural position, were only slightly affected, while considerable deterioration took place in the top and bottom portions. It is very significant that the order of deterioration of the different parts of these canes is the same as that of the invertase concentrations as found in the nodes of those regions.

It is, therefore, concluded that water, in its passage through the nodes of windrowed canes, causes the translocation of the enzymes invertase into the adjoining internodes and brings about their deterioration locally.

EFFECT OF MOISTURE IN INDUCING GERMINATION IN CANE.

The investigation carried so far clearly shows that the vital processes continue in cane long after it is lifted from the field. It is very remarkable that on wetting the cane an inversion of sucrose takes place, but the production of glucose is not proportional to the sucrose which disappears (Tables XIII [Expt. I] and XIV Expts. II and III]). This discrepancy is probably due, to some extent, to the destruction of glucose on oxidation, but is mainly caused, as the following experiment reveals, by the formation of rootlets as a result of the germination which is induced in the cane.

Portions of cane each with an internode and two nodes at the ends, the latter being sealed with paraffin after the destruction of the main bud, were exposed to moisture in a closed vessel. After eight days rootlets appeared round the nodes. The composition of the juice of the pith and rind was determined before and after the experiment and the results stated in the following table.

TABLE XVIII.

Effect of moisture on sugarcane.

Composition of juice	Pith		Rind		Remarks
	Initial	After 8 days exposure to moisture	Initial	After 8 days exposure to moisture	
Brix	16·24	15·82	17·24	15·17	Rootlets appeared round the nodes on exposure to moisture for 8 days.
Per cent. sucrose	15·06	13·22	14·52	12·91	
Per cent. glucose	1·50	1·42	1·16	1·47	

The results evidently show that moisture induced germination and that sugar disappeared due mainly to the formation of the rootlets. The effect of wetting the cane is, therefore, twofold, *viz.*, (1) to translocate the enzymes and (2) to induce germination in cane.

SPONTANEOUS DETERIORATION OF WINDROWED SUGARCANE.

Brown[1] observed from his experiments on windrowing of sugarcane that " the loss of sucrose due to spontaneous inversion is very evident, and this we can attribute very largely to the diffusion of the inverting enzyme from the green tops to the stalk." In his support, he found that canes windrowed without tops remained in better condition than those windrowed with tops on.

The results obtained at Pusa from similar experiments, however, lead to a different conclusion as is obvious from the figures in the following table.

TABLE XIX.

Cane windrowed with and without tops in shade.

Date of analysis	Days windrowed	Description	Per cent. juice expressed	Composition of juice			
				Brix	Per cent. Sucrose	Per cent. Glucose	Purity
1-2-23 . .	0	Fresh . . .	66·41	18·56	16·71	0·61	90·03
17-2-23 . .	16	Windrowed in shade without tops.	59·98	19·12	15·58	1·56	81·51
17-2-23 . .	16	Windrowed in shade with tops.	62·34	19·18	16·92	0·54	88·23

From the composition of the juice it is evident that the canes windrowed without tops deteriorated, while those left with tops on remained in excellent condition.

It was shown in the foregoing experiments that the inverting enzymes do not travel from one end to the other parts of the cane to deteriorate them, but that those present in the nodes diffuse into the adjoining internodes and cause the deterioration *locally*. It is possible that a rapid evaporation of moisture takes place through the cut end of the canes windrowed without tops and this causes the translocation of the inverting enzymes from nodes to internodes of the different parts of the canes and effect the deterioration of the latter.

SUMMARY AND CONCLUSIONS.

1. The deterioration of sugarcane stored by windrowing is effected by the enzymes present in it.

2. Enzyme activity can be efficiently checked and the cane preserved in good condition if it is kept well covered in a dry place so as to avoid rapid evaporation of moisture from the cane.

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[1] Brown, C. A. The chemistry of sugarcane and its products. *Louisiana Bull.* No. 91 (1907), p. 18.

3. On rainfall, water enters the uninjured windrowed canes through the nodes where the invertase concentration is much more than that at the internodes.

4. On the passage of water through the nodes the inverting enzymes are translocated into the internodes and cause the deterioration of the cane.

5. Moisture induces germination in sugarcane. Much of the reducing sugar, that disappears when the windrowed canes undergo deterioration on wetting, goes to form the new tissue (roots) of the germinating plants.

6. Spontaneous deterioration of windrowed cane is due to the rapid evaporation of moisture which possibly helps the diffusion of invertase from nodes to internodes of cane.

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Drainage Waters at Cawnpore

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DRAINAGE WATERS AT CAWNPORE

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Introduction.

In the year 1796, Dr. Dalton in order to study percolation and evaporation of water, thereby to investigate thoroughly the chemical and physical properties of soils, constructed a percolation gauge consisting of a cylinder three feet deep filled with soil and sunk in the ground to the level of its upper edge, arrangements being made for collecting and measuring the water which passed through. According to this plant it is clear that soil forming the drain-gauge is more loose and open in texture than the natural consolidated soil of a field, thus admitting a freer percolation. The most extensive results obtained by the use of Dalton gauges are those by Dickinson and Evans, who started this work in 1836.[1] In the year 1851, Greaves constructed drain-gauges a little different from the above, consisting of square boxes of slates three feet in depth and three feet square. One of these was filled with sand and the other with a mixture of loam, gravel and sand, trodden in and turfed. The above drain-gauges were made to study percolation and evaporation and to illustrate the influence of a crop on the two processes.[2]

At Grignon near Paris between the years 1891-97 Deherain[3] also conducted experiments on percolation in gauges, which consisted of cement tanks into which the excavated soil of the site had been refilled, the surface and sub-soil being placed in the tanks in their natural relative positions.

In 1870, Lawes and Gilbert constructed the famous drain-gauges at Rothamsted, which differ from those of others in containing undisturbed soil. Along with the observations made upon the amounts of water percolated through and evaporated from the soil, the composition of drainage waters was also studied particularly as regards the nitrate content.[4,5,6]

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[1] *Jour. Royal Agri. Soc. of Eng.*, 1845, p. 153.
[2] *Jour. Royal Agri. Soc. of Eng.*, 1881, p. 324.
[3] *Traite de Chimie Agricole*, pp. 584—99.
[4] *Jour. Royal Agri. Soc. Eng.*, 1881, pp. 311—350.
[5] *Jour. Agri. Science*, 1906, pp. 377—399.
[6] *Jour. Agri. Science*, 1920, pp. 22—43.

From the same standpoint four gauges were constructed in 1903 at the Cawnpore Experiment Station, United Provinces, India. An account of their construction and the records of drainage from 1903 to 1910 have been published by Leather[1].

On the present occasion, it is proposed to give in this paper the data obtained from the year 1910 to 1923 subsequent to the publication of the paper by Leather and to review the whole of the results, that have been obtained relating to the rain and drainage waters of Cawnpore. It will, however, be desirable first of all to give a short account of the gauges as the earlier papers on the subject are not always accessible.

All these gauges are similar to those at Rothamsted and consist of blocks of ordinary agricultural land of the Doab[2] measuring 1-1,000 acre, which were isolated and walled in and have false bottom, inse ted , eneath them ; two of these gauges are three feet deep and two are six feet deep. Below the false bottom, each gauge has an apparatus for collecting and measuring the drainage water, which percolates through.

The nitrate content of the drainage waters was determined by the modified Schloesing's method from the very beginning of the experiment to the year 1921 by the Imperial Agricultural Chemist at Pusa and from the year 1922 onwards by the Agricultural Chemist to Government, United Provinces, Cawnpore.

Character of the Seasons.

The general character of the seasons prevalent in the United Provinces, where the drain-gauges of Cawnpore are located, has previously been described in several publications by different investigators working from this as well as other standpoints ; but as this paper deals with the rainfall, percolation, evaporation, etc., it is necessary to give here a short account of it for the better understanding of the subject by those who are unacquainted with India and those to whom the previous papers may not be available.

The agricultural year of these provinces is divided into three principal seasons, each of nearly four months duration. The rainy season begins from the end of June or beginning of July and ends in October when the winter sets in and lasts up to the month of March, bringing in the hot and dry weather, which continues up to the end of June. The year bears only two principal crops, one the *kharif* (mon oon crop) and the other *rabi* (winter crop). The former starts and ends with the rainy season and the latter with the cold one. It is only in the rainy weather that the drainage really takes place as stated below. The average monthly rainfall is set out in Table I, from which it appears that out of about 34 inches of rain for the whole of the year nearly 32 inches of it falls between the months of June and October

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[1] *Mem. Dept. Agri India, Chem. Ser.*, Vol. II, No. 2, pp. 63—140.

[2] *Do* - two ; *Ab* - water, between the two rivers Ganges and Jamna.

which is the monsoon period of these provinces. From the end of October until the end of June the rainfall is restricted to showers only amounting to less than 0·5 inch for each month, which at the most merely damps the surface of the soil; consequently, drainage does not occur at the bottom of these gauges until the heavy rain of the monsoon sets in. Practically all the drainage of the year is, therefore, met with during the rainy period. Sometimes it rains very heavily amounting to 7 or 8 inches in 24 hours, when some of it runs off the land and affects the drainage accordingly.

Description of the soil.

The Cawnpore gauges are situated in the Gangetic alluvium consisting purely of very fine soil material with layers of nodular calcium carbonate (*kanker*). The soil of these gauges has not been examined chemically and appears uniform to the sight with no distinct beds of sand or clay. A stratum, 4′ to 1′ in thickness, containing some *kanker* nodules lies obliquely through gauges Nos. I and II. It is thickest in gauge No. II extending from 3′ 6″ down to the base of the gauge. In gauge No. I, there is only a little between 5′ to 6′. The two three-feet gauges contain practically no *kanker*. The fine material of these gauges possesses distinctly colloidal properties and water percolates through them with difficulty. This *kanker* does not seem to make the soil much less pervious to water. The permeability of the soil to water was determined by Leather.[1]

Prior to the construction of these gauges the land had been used for about 20 years for field experiments and manured several times with farmyard manure and poudrette.

I. Percolation and evaporation.

The annual data of the amounts of rainfall, the amount of water which has passed through the gauges, cropped and uncropped, and by differences the amounts of evaporation are given in Table II. The average yearly amounts of water percolating through six feet and three feet of bare soil are approximately one-third of the rainfall, and not half the rainfall as obtained from drain-gauges at Rothamsted[2]; this difference being due to the difference in the length of percolating columns, the character of the soils, and the nature of the seasons. The three-feet gauge yields on the average nearly one inch more drainage than the six-feet gauge. The average figures given by Leather[3] in "Drain Gauge Records at Cawnpore (1903-1910)" very nearly agree with those in this paper, and from records of 21 years (1903-1923) it can be inferred that out of the average annual rainfall at Cawnpore of about 32

[1] *Mem. Dept. Agri. India, Chem. Ser.*, Vol. II, No. 2, p. 67, (1911).
[2] *Jour. Agri. Science*, Vol. I, Pt. IV, p. 377.
[3] *Mem. Dept. Agri. India, Chem. Ser.*, Vol. II, No. 2, p. 75 (1911).

to 34 inches, 10 to 12 inches percolates through the soil and the rest evaporates.

On comparing the average figures obtained from fallow gauges at Cawnpore with those at Pusa[1] and at Rothamsted, [2, 3] as given in Table III, it is clearly seen that of the three places Rothamsted has got the least quantity of rainfall and the greatest amount of drainage water, at Pusa the reverse is the case. It is interesting, to note here that the place with the heaviest rainfall has got the least percolation figure and *vice versâ*. This may be due to differences in the characters of the soil, temperatures, humidity and other physical factors.

Table II records the yearly amounts of drainage and evaporation from the year 1910-11 to 1923-24. Before studying these figures the treatment which the soils of different gauges had undergone during these years, should first be considered. From the year 1908-09 to 1913-14, gauges Nos. I and IV were continually cropped. Cropping was continued on gauge No. I up to the year 1917-18, while it was discontinued on gauge No. IV and in its place gauges Nos. II and III were utilized for the purpose during the next four years as shown in Table IV.

Drainage from fallow gauges.

Turning now to Table II and considering the relation between the annual amounts of the rainfall and the drainage, it is generally found that the heavier is the rain the more is the drainage. Thus with 19·78 inches of rain, the drainage from fallow gauge No. II was 3·50 inches, with 25·76 inches of rain the drainage was 5·35 inches, with 33·91 inches 8·60 inches, with 42·47 inches 16·97 inches and with 58·41 inches 23·88 inches. The same conclusion was arrived at by Miller[4] at Rothamsted and was expressed as a rule that the high rainfall is coincident with a relatively high amount of drainage.

Drainage from gauges of the same depth.

From the year 1918 to 1924, all the gauges were kept fallow and no crops were grown on them. Working under similar conditions and with gauges of the same size, gauge No. I should have given the same drainage figures as gauge No. II and gauge No. III as gauge No. IV, but actually they have not done so.

Every year there has been some difference in the quantity of water draining through the gauges of the same size, sometimes one giving more drainage than the other and *vice versâ*. Although this difference is not much and ranges from 0·4

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[1] *Mem. Dept. Agri. India, Chem. Ser.*, Vol. II, No. 2, p. 75 (1911).
[2] *Jour. Agri. Science*, Vol. I, Pt. IV, p. 377.
[3] *Jour. Royal Agri. Soc. Eng.*, 1881, Vol. XVII, p. 277.
[4] *Jour. Agri. Science*, Vol. I, 1905-06, p. 381.

to 1·7 inches still it is noticeable. This is partly due to the difference in the power of retention of the soil in the two gauges owing to slight difference in their composition and also partly to evaporation.

Drainage from gauges of different depths.

To compare the drainage from gauges of different depths, gauges Nos. II and III are taken into consideration, because both of them remained almost always fallow from the year 1910 to 1924, except for two or three years as shown in Table IV. The three-feet gauge No. III has almost every year, except in the years 1913-14 and 1916-17, given greater quantity of drainage water, ranging from 0·7 to 6 inches, than the six-feet gauge No. II due most probably to the shorter column of earth in the former through which the water has to percolate. In the year 1916-17, the three-feet gauge was under crop and has therefore given less drainage than the six-feet gauge. In the year 1913 also, No. III gauge has given less percolation than No. II. This shows that in addition to the length of the column of earth there may be other factors, such as nature of the soil, character of the season, which may be exerting their influence upon the quantity of percolating water. Generally, the difference in percolations through gauges of various sizes remains below two inches when the rainfall is normal and confirms the findings of Leather[1]; but it appears to increase up to six inches with the increase in the quantity of rainfall.

The range of rainfall during the fourteen years from 1910-24 is seen to have been considerable from 11·45 inches to 58·41 inches. The twenty-one years of experiment has thus afforded examples of extreme rainfall and drought such as can be found only in much longer periods of observation.

The year 1918-19 can be said to be one of drought, the rainfall amounting only 11·45 inches and consequently there was no drainage at all. It was only on two days that the rain fell a little more than an inch, sufficient enough only to moisten the soil of the gauges.

With this very large variation in the rainfall, we have a similar variation though not greater as shown at Rothamsted[2] in the amount of water passing through the bare soil of the gauges as shown in Graph I. Leaving aside the drainage through the cropped soil, the quantity of water, expressed in percentages of the rainfall and percolating through the fallow gauges Nos. II and III, has varied from 17·69 to 41·88 inches with the mean of 29·78, and 16·18 to 52·29 inches with the mean of 34·23 respectively. Thus the variations in the quantities of water percolating through a three-feet gauge are greater than those through a six-feet gauge. The cause of this variation in the amount of water percolating through the soil may be due partly

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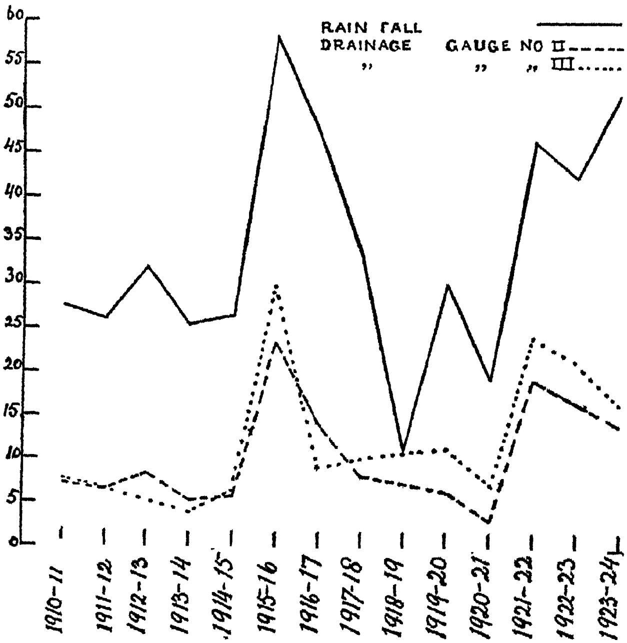
[1] *Mem. Dept. Agri. India, Chem. Ser.*, Vol. II, No. 2, pp. 63=140

[2] *Jour. Royal Agri. Soc. Eng.*, 1881, p. 315.

to the amount of evaporation from the surface which has taken place at the same time, and which is also shown in Table II, and partly to retention by the soil.



GRAPH I. Showing yearly variations in the rainfall and the drainage waters from gauges Nos II and III.

Drainage from cropped gauges.

Table V gives the annual rainfall and drainage from the cropped gauges. As has already been stated, the drainage almost wholly takes place during the rainy season; therefore the effect of a crop upon drainage can best be observed only by growing a *kharif* crop, and can be seen from the above table.

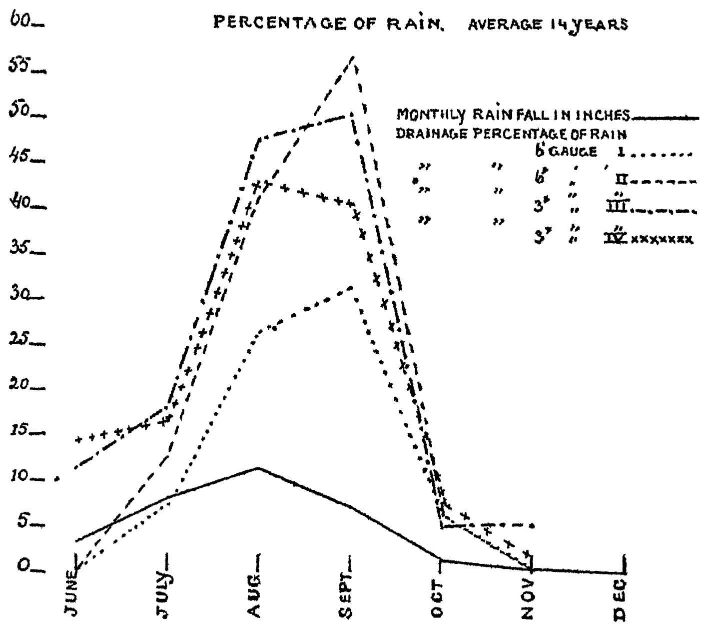
Comparing the drainage from a cropped land with that from a bare fallow it can be seen from Tables II and V that cropping reduces the drainage considerably. This reduction varies within wide limits and when the year is a dry one like that of 1913-14 and 1914-15, the drainage becomes almost nothing.

Turning now to Table V and keeping in mind that the heavier the rainfall the more the drainage it can be seen, though not so clearly, owing to good many factors coming into play, that when the crop is heavier the drainage is less and also evaporation is more as shown in Table VI. For instance, during the years 1911-12 and 1914-15, there was nearly, the same quantity of rainfall, *i.e.*, about 26 inches, and

accordingly the quantities of drainage waters from uncropped gauges was also nearly the same, *i.e.*, about 6 inches. But such was not the case with cropped gauges; there was a great difference in drainage waters and it varied inversely as the crops, namely, the heavier the crop the less the drainage.

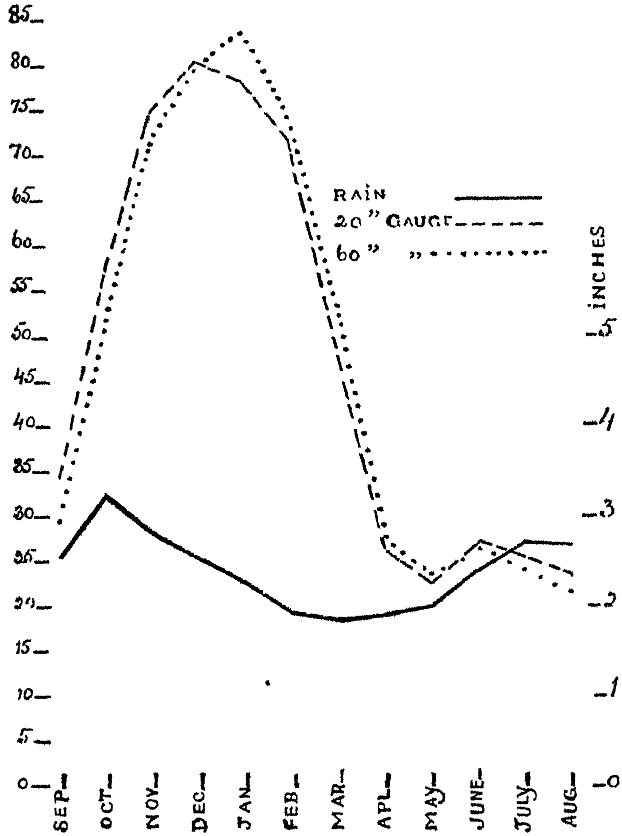
The average results of monthly percolation along with temperature are set out in Table VII and show that the rainfall and the drainage begin in June when the temperature is at its highest and the latter goes on increasing along with the former, which cools the temperature down. The maximum amount of drainage takes place in the months of August and September, when the temperature remains nearly constant. In the month of October there is a sudden decrease in the drainage water, which corresponds with the rainfall as well as the temperature and is brought to its minimum in November. During the remaining part of the year there is no drainage at all due to the very small quantities of rain, which fall at long intervals and are not sufficient to percolate through six or three feet of the soil.

The monthly differences between the drainage of six-feet gauge No. II and that of the three-feet gauge No. III both of which remained almost fallow throughout the experiment, and also between the drainage of six-feet gauge No. I and three-feet gauge No. IV which remained under crops for some years as shown in Table



GRAPH II.(*a*) Monthly rainfall and drainage through 6 feet and 3 feet gauges of Cawnpore fallow soil

VII, are not so regular as found by Miller[1] at Rothamsted, where a regularity has been marked. This can be clearly noticed from Graph II (*a*) and II (*b*) (Miller's).



GRAPH NO. II (*b*) (MILLER).—Monthly rainfall and drainage through 20" and 60" of Rothamsted soil

Percentage of rain. Average : 5 years.

In both these graphs the drainage is calculated in percentage of rainfall. These monthly differences are difficult to account for and may be due to the variations in temperatures, pressure, viscosity, etc.

EVAPORATION.

In Table II are given the quantities of water evaporated annually from different gauges. They are expressed in inches as well as percentage of rainfall. Leather,

[1] *Jour. Agri. Science*, Vol. I, 1905-06, p. 382.

when comparing the records of India with those of Rothamsted, says in his memoir[1] :—"At the English station, the gauges have shown that the amount of percolation varies directly with the rainfall, whilst the amount, which evaporates, is approximately constant and varies only slightly with the rainfall, being rather greater in a wet year. Thus at Rothamsted with 41″ rainfall, the drainage was 25″, and evaporation 16″; with a rainfall of 19·5″, the drainage was 6″ and the evaporation 13″. The amount of water which evaporates per unit of time from a soil depends largely on whether the water has to travel a long or a short distance to the surface; hence during wet weather, when the surface soil is moist, evaporation will necessarily be high. Of course this is only one of the determining factors, the character of the soil, and the atmospheric temperature and humidity being others; but for any one place, that is, for the same soil, the amount, which evaporates, will be greater in wet than in dry weather."

The statement, "The amount which evaporates....................being rather greater in a wet year" can only hold good when absolute amounts of water evaporated are referred to; but if the quantity of water evaporated is considered in relation to the amount of rainfall, then it is found by a careful study of Leather's figures as well as of Table II that when the rainfall is more, evaporation is considerably reduced. Thus from the figures quoted by Leather, it will be seen that when the rainfall is 19·5 inches, the evaporation is 13 inches; therefore when the rainfall is 41 inches, and if the relation between the rainfall and the evaporation is in direct proportion, the evaporation should be 27·3 inches (*viz.*, 19·5 : 41 : 13 : 27·3). Instead of that, however, the actual figure of evaporation quoted by him is 16 inches. Therefore the amount of water which evaporates, does not increase with the increase of rainfall; rather on the contrary, it is decreased. This is still more obvious when the figures of evaporation are calculated in terms of the percentage of rainfall. For instance, with the rainfall of 19·7 inches, the percentage of water evaporated from fallow gauge No. II is 82·31 per cent., with 33·91 inches, 74·64 per cent., with 47·31 inches, 69·67 per cent., and with 58·41 inches, 59·12 per cent. The same is the case with evaporation from fallow gauge No. III with slight difference here and there. Graph No. III also illustrates this fact very clearly, namely, wetter the year the less is the evaporation.

The difference in the evaporation from the fallow soils of gauges of different sizes is quite clear from the annual figures given in Table II, which shows that the evaporation has nearly every year been greater from the soil of the six-feet gauge than from the soil of the three-feet gauge. This excess of evaporation varies from 0·5 to 6 inches, and confirms the results of Lawes, Gilbert and Warrington,[2] and is due to the capillary power of the soil which is capable of bringing water to the surface from a depth of six feet.

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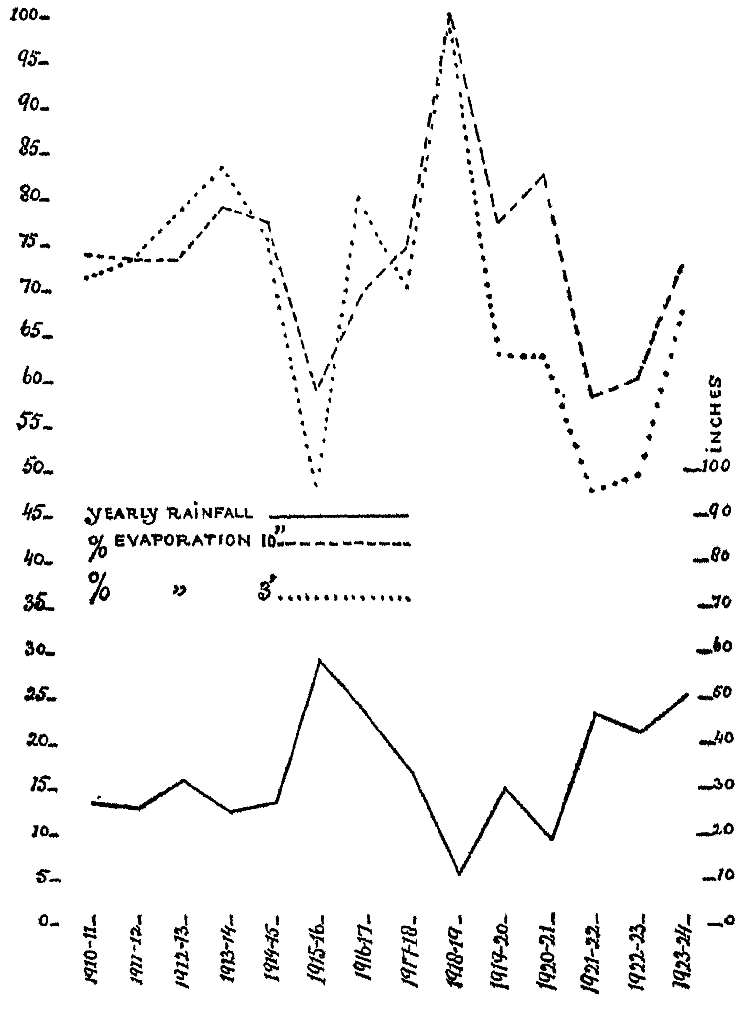
[1] *Mem. Dept. Agri India, Chem Ser.*, Vol. II, No. 2, p. 73, 1911.
[2] *Jour. Royal Agri. Soc. Eng*, 1881, p. 278.



GRAPH III Yearly rainfall and the percentage of water evaporation from 6 feet and 3 feet gauges

The yearly rainfall and evaporation from cropped gauges Nos. I and IV are given in Table VI which clearly shows that the total evaporation from cropped gauges is always far higher than that from the fallow ones due to the combined effect of evaporation from the surface and transpiration through the plants.

With regard to monthly rainfall and evaporation the average results set out in Table VIII indicate that the evaporation expressed as percentage of the rain is

greatest in the month of November, when the rainfall is at its minimum, and least in the month of September when the rainfall begins to decline.

II. Composition of the Drainage.

Amount of nitrate in the drainage waters.

Of all the plant foods found in the soil and liable to be washed away, nitrogen is the most important and was determined in the drainage waters of Cawnpore gauges. The soluble forms in which nitrogen is found in the soil are (i) some forms of organic nitrogen, (ii) ammoniacal nitrogen, (iii) nitrous nitrogen, and (iv) nitric nitrogen. The first three forms are transitional products and as such cannot accumulate in the soil and, therefore, their determination in the drainage waters was not considered desirable. Besides, the determination of ammoniacal nitrogen in the drainage waters at Cawnpore was carried out in the very beginning of the experiment, but the quantity of ammonia found was negligibly small and therefore its estimation was discontinued.

The nitric nitrogen, being the final product, accumulates in the soil. Its quantity, though small, is estimable in the drainage waters and was therefore continually determined by the Schloesing's method. The yearly amounts of nitric nitrogen in drainage water obtained from Cawnpore gauges during the years 1910-23 are expressed as parts per million of water and also as lb. per acre in Table IX.

Bare fallow land.

In a previous paper by Leather,[1] "the quantity of nitrate in drainage waters from fallow gauges was shown to vary very largely with the season, having been over 100 lb. and even 200 lb. per acre in individual years of heavy rainfall at Cawnpore; whilst in years of small rainfall the amount of nitrate fell to very normal quantity"; the average yearly amounts of nitric nitrogen in drainage waters obtained at Cawnpore during the first seven years of the experiments (1903-09) were as shown below :—

Gauge No.	lb. per acre
I	62·10
II	81·10
III	44·80
IV	38·20

From the perusal of the figures given in Table IX, it appears that the annual quantity of nitrate in drainage waters from fallow gauges does not vary so much as it was in the beginning of the experiment. It has never gone above 64 lb. nor below 11 lb. per acre. The average annual quantities of nitric nitrogen in drainage waters

[1] *Mem. Dept. Agri. India, Chem. Ser.*, Vol. II, No. 2 (1911).

during the subsequent years (1910-24) have also gone down and amount to 14·82 lb. per acre from gauge No. I, 24·07 lb. from gauge No. II, 30·47 lb. from gauge No. III, and 17·72 lb. from gauge No. IV.

The yearly amounts of nitrate washed out of the fallow soils during the period of experiment are still subject to large fluctuations from year to year though not so much as noticed by Leather in the very beginning of the experiments, partly owing to differences in the rainfall and partly to the distribution of the rains. These irregularities are much reduced by taking several years' averages, and the results are :—

Average nitric nitrogen in drainage waters, lb. per acre.

Period	6 foot Gauge No. II	3 foot Gauge No. III
5 years average (1905-09)	81·14	47·76
4 „ „ (1910-13)	35·73	32·58
5 „ „ (1919-24)	24·27	29·02

During the first few years of the experiment the loss of nitrogen was very high being 81·14 lb. per acre from six-feet gauge No. II. During the last five years the losses amount to 24·27 and 29·02 lb. per acre from gauges Nos. II and III respectively. Thus there appears a tendency for the nitrate content of drainage waters to fall off as the time goes on and may be due to the gradual exhaustion of the unmanured soil of the gauges. In the above statement the years from 1914-19 are left out because gauges Nos. II and III were under crops during the years 1914-18, while in the year 1918-19 there was no drainage at all due to scanty rainfall.

This slow decline in the nitrate content of the drainage waters seems to correspond with the results obtained at Rothamsted by Russell and Richards,[1] and is made clearer when the quantity of nitrogen as nitrate washed out for every inch of rain at the two places is taken into consideration.

Average amounts of nitrogen as nitrate washed out for every inch of rain at Rothamsted and Cawnpore.

Years	Nitrogen washed out per inch of rain lb. per acre — Rothamsted		Years	Nitrogen washed out per inch of rain lb. per acre — Cawnpore	
	20″ Gauge	60″ Gauge		3′ Gauge	6′ Gauge
1877-1888	1·21	1·51	1905-1909	1·5	2·6
1888-1900	1·13	1·09	1910-1915	1·2	1·1
1901-1912	0·85	0·88	1919-1924	0·82	0·66
1913-1915	0·82	0·72			

[1] *Jour. Agri. Science*, Vol. X, 1920, p. 27.

Thus it is seen that the quantity of nitrogen washed out by rain was very high n the beginning of the experiment at both the places, especially at Cawnpore. This fact will be explained later on. After that there has always been a decline, which is very gradual in the case of Rothamsted but not so in Cawnpore.

Another fact noticed by Leather[1] was the very large amount of nitrate found in the water at Cawnpore as compared with that at Rothamsted. This was the case at least for some years after the beginning of the experiment, simply because prior to the construction of gauges at Cawnpore, the land was regularly manured with the farmyard manure and the poudrette, the nitrogen of which was being slowly and gradually converted into nitric acid. As long as the effect of those manures remained, the nitrogen content of the drainage waters was found to be very high; but as soon as this influence was removed and the land returned to its normal condition the nitrogen contents of the waters were never found to be so high and appeared to approach nearly those obtained at Rothamsted, as can be seen from the averages of the last five years of the two places.

The average (1919-24) losses of nitrogen from six-feet and three-feet Cawnpore gauges were 24·27 and 29·02 lb. per acre respectively; while those (1910-14) from 60″ and 20″ Rothamsted gauges were 23·94 and 24·48 lb. respectively. Thus the nitrogen content of the drainage waters of Cawnpore gauges, though approaching those of Rothamsted, are still found to be higher and are due to the higher temperature of the Indian soils where nitrification is more rapid and larger amounts of nitrates are found in drainage waters.

Total amount of nitrogen removed from the soil in gauges.

The total amount of nitrogen in the drainage water from different gauges during the whole period of 21 years (1903-23) is as follows :—

	lb. per acre
6 feet gauge No. I	642·08
6 „ „ „ II	746·27
3 „ „ „ III	744·92
3 „ „ „ IV	457·50

Gauges Nos. II and III, which remained fallow for nearly the whole period, though differing in size, have on the whole given very similar results. Gauges Nos. I and IV remained under crops for a different number of years and therefore have given different figures and in either case less than those from the fallow ones.

The close similarity between 746·27 lb. of nitrate washed out from the six-feet gauge and 744·27 lb. washed out from the three-feet gauge shows that the nitrate comes only from the surface layers and not at all from the lower depths. This

[1] *Mem. Dept. Agri. India, Chem. Ser.*, Vol. II, No. 2 (1911).

fact confirms the view of Russell and Richards,[1] who working on 20″ and 60″ gauges have stated that the lower 40 inches have contributed no nitrate to the drainage waters and thus there is no reason to go below the top nine inches for the source of nitrate.

Comparing the losses of nitrate from the gauges of different depths the average figures given at the foot of Table IX and n X clearly show that the loss is generally more from the three-feet gauge than that from the six-feet gauge. The main reason for this difference may be due to the fact that the rain falling on the surface of the soil dissolves out its nitrate content. The solution thus formed starts on its downward movement where some of the solution is retained. The longer the distance, the more of the solution is retained and the quantity of nitrate passing out will accordingly be reduced. Although in the majority of years the quantity of nitrate passing out of the deeper drain-gauges is less than that passing out of the shallow gauges ; still in some years a reverse phenomenon is observed to occur, which indicates that the distance is not the only factor which influences the quantity of nitrate in drainage waters but there are others too and they may be the character of the season and the nature of the soil.

Cropped land.

Gauge No. I was continually under crops from the year 1910 to 1918, while gauge No. IV was under crops from the year 1910 to 1916. The total quantities of nitric nitrogen lost in drainage waters from gauges Nos. I and IV during the above periods comes to 30·37 and 31·09 lb. per acre with the average of 3·79 and 5·18 respectively. The corresponding fallow gauges Nos. II and III have during the same periods given the total losses of nitrogen amounting to 215·55 and 226·74 lb. per acre with averages of 26·94 and 37·79 respectively. On dividing 26·94 by 3·79 and 37·79 by 5·18 the quotient in both cases comes to 7·2 which clearly shows that the fallow land loses about 7 times more nitrogen than the cropped one. It will be an intere ting problem, therefore, to investigate whether in the light of the above data, it is more economical to keep the land under a crop than to leave it fallow during the rainy season and whether this statement will hold good for soils in general. The smaller amount of nitrate in the drainage from the cropped gauges may be accounted for by crop assimilation, by the fact that the drainage was probably insufficient to wash out the nitrate completely and by the activities of various micro-organisms present in the cropped land.

The period when most nitrate leaves the gauges.

From the record of nitrate content as set out in Table X, the period when the greater part of the nitrate passes out of each gauge can be easily determined. These monthly results show the amounts of nitrogen withdrawn from the soil in the different

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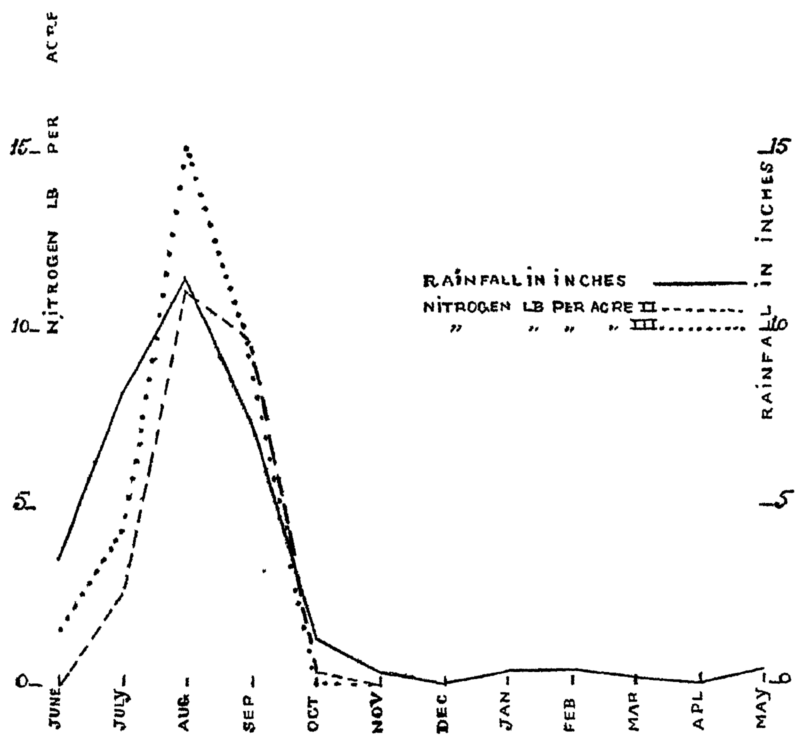
[1] *Jour. Agri. Science*, Vol. X, 1920, p. 36.

months of the year. The loss of nitrate begins in the month of June, followed by a fair and gradual rise in July and a rapid rise in the month of August when the maximum loss occurs. This is succeeded by a fall in September which continues till the month of November when the loss reaches its minimum. When considering the relation between the loss of nitric nitrogen and the rainfall it appears from the figures given in Table X that the loss of nitrogen from the gauges varies directly as the rainfall and the drainage. This is best shown in Graph IV. Therefore the



GRAPH IV. Showing the monthly rainfall and the loss of nitrogen from different gauges at Cawnpore

heavier the rainfall the more is the drainage and the greater is the loss of nitrogen from the soil. The same fact is also noticeable from Table IX, which contains the annual amounts of rainfall, drainage and the loss of nitrogen. The year 1923-24 is an exception to the above, because the rain fell so heavily on certain occasions that the soils of the gauges were flooded over, resulting in comparatively less drainage and consequently less loss of nitrate.

Conclusions.

From the data given above the following conclusions may be drawn :—

(1) All the drainage of the year is practically met with during the rainy season, extending from June to October. During this period the rainfall amounts to 32 inches out of the yearly average of 34 inches. For the remaining months of the year the average comes to only 0·5 inch of rain per month.

(2) The relation between the rainfall and the drainage of any particular place appears to be that the heavier the rainfall the more is the drainage.

(3) The difference in the quantities of water percolating through gauges of the same size always varies; but it generally remains below two inches. The variations are greater in the case of three-feet gauges than in the case of six-feet ones.

(4) Shallow gauges give greater quantities of drainage waters than the deeper ones.

(5) Cropping reduces the drainage considerably and the heavier the crop the less the drainage and the more is the evaporation.

(6) The maximum amount of drainage takes place in the months of August and September.

(7) With the increase in rainfall, evaporation is decreased. This is more evident when the evaporation is calculated as percentage of rainfall.

(8) Evaporation is always far higher from a cropped gauge than from a fallow one, due to the combined action of evaporation from the surface and transpiration through plants.

(9) Evaporation is nearly always greater from a deeper gauge than from a shallow one.

(10) The quantity of nitrate in drainage waters appears to fall off gradually as the time goes on.

(11) The fallow gauges of different sizes give nearly the same quantities of nitrogen in their drainage waters. The nitrate, therefore, comes only from the surface soil and not from the lower depths.

(12) Fallow gauges lose about 7 times more nitrogen in their drainage waters than the cropped ones.

(13) The maximum loss of nitrate in drainage takes place in the month of August.

(14) The heavier the rainfall, the more is the drainage and consequently greater is the loss of nitrogen.

Acknowledgments.

The author takes this opportunity to express his thanks to Messrs. Low, Dey and Sabnis of the Agricultural Department of the United Provinces, for their valuable suggestions, and to Rai Sahib S. C. Banerjee for his help in analytical work.

TABLE I.

Average monthly rainfall.

Month	Average of 19 years; 1891-1919	Average of 14 years; 1910-1923	Average of 33 years; 1891-1924
	inches	inches	inches
June	2·90	3·46	3·18
July	10·04	8·10	9·07
August	11·09	11·49	11·79
September	6·33	7·47	6·90
October	1·28	1·38	1·33
November	0·22	0·49	0·35
December	0·36	0·11	0·23
January	0·47	0·48	0·47
February	0·54	0·44	0·49
March	0·13	0·29	0·21
April	0·20	0·08	0·14
May	0·30	0·47	0·38

TABLE II.

Yearly amounts of drainage and evaporation through 6 feet and 3 feet gauges, 1910-1924.

Year	Rain-fall	6 FEET GAUGE No. I				6 FEET GAUGE No. II				3 FEET GAUGE No. III				3 FEET GAUGE No. IV			
		Drainage	Drainage	Evaporation	Evaporation	Drainage	Drainage	Evaporation	Evaporation	Drainage	Drainage	Evaporation	Evaporation	Drainage	Drainage	Evaporation	Evaporation
	inches	inches	per cent.	inches	per cent.	inches	per cent.	inches	per cent.	inches	per cent.	inches	per cent.	inches	per cent.	inches	per cent.
1910-11 . .	27·57	4·39	15·92	23·18	84·07	7·16	25·97	20·41	74·03	7·86	28·51	19·71	71·49	6·04	21·91	21·53	78·09
1911-12 . .	26·10	1·50	5·75	24·60	94·25	6·88	26·36	19·22	73·61	6·85	26·36	19·22	73·64	6·33	24·25	19·77	75·75
1912-13 . .	32·12	3·20	9·96	28·92	90·04	8·49	26·43	23·63	73·57	..	..	..	..	..	..	..	..
1913-14 . .	25·76	0·004	0·01	25·756	99·99	5·35	20·76	20·41	79·24	4·17	16·18	21·59	83·82	0·21	0·81	25·55	99·19
1914-15 . .	26·70	0·004	0·01	26·696	99·99	6·00	22·47	20·70	77·53	6·52	24·42	20·18	75·58	..	..	26·70	100·00
1915-16 . .	58·41	9·14	15·65	49·27	84·35	23·88	40·88	34·53	59·12	30·00	51·36	28·41	48·64	15·81	27·07	42·60	72·93
1916-17 . .	47·31	1·93	4·08	45·38	95·92	14·35	30·33	32·96	69·67	9·39	19·85	37·92	80·15	19·00	40·16	28·31	59·84
1917-18 . .	33·91	3·88	11·44	30·03	88·56	8·60	25·36	25·31	74·64	10·10	29·78	23·81	70·22	12·88	37·98	21·03	62·02
1918-19 . .	11·45	..	..	11·45	100·00	..	..	11·45	100·00	..	..	11·45	100·00	..	..	11·45	100·00
1919-20 . .	30·15	6·31	20·93	23·84	79·07	6·86	22·75	23·29	77·25	11·22	37·15	18·93	62·85	10·32	34·23	19·83	65·77
1920-21 . .	19·78	5·21	26·34	14·57	73·66	3·50	17·69	16·28	82·31	7·48	37·80	12·30	62·20	5·80	29·32	13·98	70·68
1921-22 . .	46·30	19·84	42·85	26·46	57·15	19·39	41·88	26·91	58·12	24·21	52·29	22·09	47·71	23·27	50·26	23·03	49·74
1922-23 . .	42·47	18·51	43·58	23·96	56·42	16·97	39·96	25·50	60·04	21·42	50·44	21·05	49·56	21·99	51·79	20·48	48·22
1923-24 . .	51·79	15·26	29·46	36·53	70·54	14·34	27·69	37·45	72·31	16·95	32·75	34·84	67·25	17·59	33·96	34·20	66·04
TOTAL .	479·82	89·17	..	390·64	..	141·77	..	338·05	..	156·20	..	291·50	..	139·24	..	308·46	..
AVERAGE .	34·27	6·37	..	27·90	..	10·13	..	24·14	..	11·16	..	20·82	..	9·94	..	22·03	..

TABLE III.

Year	Rainfall in inches	Drainage at Cawnpore in inches		Drainage at Pusa in inches		Drainage at Rothamsted in inches		
		6′ gauge	3′ gauge	6′ gauge	3′ gauge	20″ gauge	40″ gauge	60″ gauge
1870-1915 . . .	28·94	..	..	..	..	14·74	15·42	14·78
1905-1924 . . .	32·72	11·05	12·01	..	..	.	.	..
1906-1910 . . .	42·41	..	..	10·44	12·50	..	..	..

TABLE IV.

Crop and their quantities grown on the soil of gauges Nos. I, II, III and IV during the period of experiments.

Year	6 FEET GAUGE No. I		6 FEET GAUGE No. II		3 FEET GAUGE No. III		3 FEET GAUGE No. IV	
	Total crop lb. per acre		Total crop lb. per acre		Total crop lb. per acre		Total crop lb. per acre	
1910-11	Rabi—Wheat	733 lb. of grain only	....		....		Rabi—Wheat	489 lb. of grain only
1911-12	Kharif—Juar	6,988	....		....		Kharif—Juar	4,326
	Rabi—Wheat	559					Rabi—Wheat	812
1912-13	Kharif—Sann-hemp (cut green)	10,336	....		....		Kharif—Sann-hemp (allowed to ripen)	9,663
	Rabi—Wheat	2,671						
1913-14	Kharif—Sann-hemp (cut green)	6,555	....		....		Kharif—Sann-hemp (allowed to ripen)	6,367
	Rabi—Wheat	1,354						
1914-15	Kharif—Sann-hemp	9,070	Rabi—Wheat	3,175	Kharif—Sann-hemp (allowed to ripen)	2,580	....	
	Rabi—Wheat	4,423						
1915-16	Kharif—Sann-hemp (air dry)	13,007	Fallow		....		Kharif—Sann-hemp (air-dry)	125,012
	Rabi—Wheat	5,108	Rabi—Wheat	2,098				
1916-17	Kharif—Sann-hemp (cut green)	19,000	Rabi—Wheat	3,463	Kharif—Sann-hemp (allowed to ripen)	15,000	....	
	Rabi—Wheat	5,274						
1917-18	Rabi—Wheat	6,305	Rabi—Wheat	2,679	....		....	

TABLE V.

Yearly amount of rainfall and drainage from cropped gauges.

Year	Rainfall	6 feet gauge No. 1				3 feet gauge No. IV			
		Drainage	Drainage	Crops		Drainage	Drainage	Crops	
	inches	inches	per cent.		lb. per acre	inches	per cent.		lb. per acre
1910-11	27·57	4·380	15·92	Wheat	733	6·640	21·91	Wheat	489
1911-12	26·10	1·500	5·75	Juar	6,988	6·330	24·25	Juar	4,326
				Wheat	599			Wheat	812
1912-13	32·12	3·200	9·96	Sann-hemp	10,336	..	..	Sann-hemp	9,683
				Wheat	2,671				
1913-14	25·76	0·004	0·01	Sann-hemp	6,555	0·210	0·81	Sann-hemp	6,367
				Wheat	1,854				
1914-15	26·70	0·004	0·01	Sann-hemp	9,070	0·003	..	....	
				Wheat	4,423				
1915-16	58·41	9·140	15·65	Sann-hemp	13,007	15·810	27·07	Sann-hemp	125,011
				Wheat	5,108				
1916-17	47·31	1·930	4·08	Sann-hemp	19,000	..	..	....	
				Wheat	5,274				
1917-18	33·91	3·880	11·44	Wheat	6,305	..	..	....	

Table VI.

Yearly amount of rainfall and evaporation from cropped gauges.

Year	Rainfall	6 feet gauge No. I				3 feet gauge No. IV			
		Evaporation	Evaporation	Crops		Evaporation	Evaporation	Crops	
	inches	inches	per cent.		lb. per acre	inches	per cent.		lb. per acre
1910-11 .	27·57	23·18	82·34	Wheat . . .	733	21·53	78·09	Wheat . . .	489
1911-12 .	26·10	24·60	94·25	Juar . . .	6,988	19·77	75·75	Juar . . .	4,326
				Wheat . . .	599			Wheat . . .	812
1912-13 .	32·12	28·92	90 04	Sann-hemp . .	10,336	32·12	100·00	Sann-hemp . .	9,683
				Wheat . . .	2,671				
1913-14 .	25·76	25·76	99 99	Sann-hemp . .	6,555	25·55	99·19	Sann-hemp . .	6,367
				Wheat . . .	1,854				
1914-15 .	26·70	26·70	99 99	Sann-hemp . .	9.070	26·70	99·99	....	
				Wheat . . .	4.423				
1915-16 .	58·41	49·27	84·35	Sann-hemp . .	13,007	42·60	72·93	Sann-hemp . .	125,011
				Wheat . . .	5,108				
1916-17 .	47·31	45·38	95·92	Sann-hemp . .	19,000	28·31	59·84	....	
				Wheat . . .	5.274				
1917-18 .	33·91	30·03	88·56	Wheat . . .	6,305	21·03	62·02	....	

TABLE VII.

Monthly amounts of drainage through 6 feet and 3 feet gauges and the temperature average of 14 years.

1910-11 to 1923-24	Rainfall	Drainage				Drainage percentage of rain				Temperature
		6 feet gauge I	6 feet gauge II	3 feet gauge III	3 feet gauge IV	6 feet gauge I	6 feet gauge II	3 feet gauges III	3 feet gauge IV	
	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	
Month—										
June	3·46	0·010	0·0002	0·39	0 50	0·44	0·006	11·27	14·45	94·0
July	8·10	0·630	1·0400	1·46	1·36	7·78	12·840	18·02	16·79	89·1
August	11·49	3·280	4·7600	5·47	4·94	26·55	41·430	47·61	43 00	87·2
September	7·47	2·340	4·2400	3·75	3·03	31·32	56·740	50·20	40·56	86·3
October	1·38	0·090	0·0900	0·07	0·11	6·52	6·520	5·07	7·97	80·5
November	0·49	0·001	0·0060	0·02	0·01	0·20	0·120	5 10	2·04	70·4
December	0·11	..	..	..	..	..	..	..	..	64·3
January	0·48	..	..	..	..	..	..	..	..	57·7
February	0·44	..	..	..	..	..	..	..	..	61·8
March	0·29	..	..	..	..	..	..	..	..	71·3
April	0·08	..	..	..	..	..	..	..	..	80·5
May	0·47	..	..	..	..	..	..	..	..	86·1

TABLE VIII.

Monthly amounts of evoporation through 6 feet and 3 feet gauges and the temperature average of 14 years.

1910-11 to 1923-24	Rainfall	Evaporation				Evaporation percentage of rain				Temperature
		6 feet gauge I	6feet gauge II	3 feet gauge III	3 feet gauge IV	6 feet gauge I	6 feet gauge II	3 feet gauge III	3 feet gauge IV	
Month—	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	Inches	
June . . .	3·46	3·45	3·46	3·07	2·96	99·71	99·99	87·73	85·55	94·0
July . . .	8·10	7·47	7·06	6·64	6·74	92·22	87·16	82·00	83·21	89·1
August . . .	11·49	8·21	6·73	6·02	6·55	71·45	58·57	52·39	57·01	87·2
September . .	7·47	5·13	3·23	3·72	4·44	58·68	43·24	49·80	59·44	86·3
October . .	1·38	1·29	1·29	1·31	1·24	93·48	93·48	94·60	92·03	80·5
November . .	0·49	0·49	0·49	0·47	0·48	99·80	99·88	95·91	97·95	70·4
December . .	0·11	..	..	..	..	..	..	..	..	64·3
January . .	0·48	..	..	..	..	..	..	..	..	57·7
February . .	0·14	..	..	..	..	..	..	..	..	61·8
March . . .	0·29	..	..	..	..	..	..	..	..	71·3
April . . .	0·08	..	..	..	..	..	..	..	..	80·5
May . . .	0·47	..	..	..	..	..	..	..	..	86·1

TABLE IX.

Yearly amounts of nitrogen as nitrates in drainage waters, 1910-1924.

Year	Rainfall	DRAINAGE				NITROGEN PARTS PER MILLION				NITROGEN LB. PER ACRE			
		GAUGES				GAUGES				GAUGES			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
	Inches	6 feet	6 feet	3 feet	3 feet	6 feet	6 feet	3 feet	3 feet	6 feet	6 feet	3 feet	3 feet
1910-11	27·57	4·390	7·16	7·86	6·040	14·52	96·01	72·69	5·22	1·49	23·29	34·36	1·0000
1911-12	26·10	1·500	6·88	6·85	6 330	26·71	112·40	104·31	36·59	3·16	42·65	57·03	6·7500
1912-13	32·12	3·200	8·49	..	..	32·72	204·33	112·58	106·34	4·35	53·09	14·12	2·9300
1913-14	25·76	0·004	5·35	4·17	0 210	55·80	191·12	187·95	8·57	0·05	23·88	24·81	0·1700
1914-15	26·70	0 004	6·00	6·52	0 003	149·40	199·57	160·93	4·05	0·05	30·43	46·34	0·0026
1915-16	58·41	9·140	23·88	30·00	15·810	495·64	486·81	78·12	95·20	3·90	24·53	50·08	20·2100
1916-17	47·31	1·930	14·35	9·39	19 000	470·34	117 83	44·75	42·59	1·76	9·63	8·45	24·5500
1917-18	33·91	3·880	8·00	10·10	12 880	692·05	20·66	132·77	100·62	15 61	8 05	46·28	57·5000
1918-19	11·45	..	..	..	..	..	..	..	..	..	..	..	..
1919-20	30·15	6·310	6·86	11 22	10·320	283·67	81·95	79·65	97·88	40·43	27·55	55·16	46·8700
1920-21	19·78	5·210	3 50	7·48	5·800	70 19	68·91	28·27	30·41	24·74	11·86	25·27	20·4500
1921-22	46·30	19·840	19·39	24·21	23·270	129·62	37·25	45·99	58·74	64·48	43·89	27·16	31·4200
1922-23	42·47	18·510	16·97	21·42	21·990	33·44	38·67	22·12	22·26	30·57	24·55	23·01	24·6900
1923-24	51·79	15·260	14·34	16·95	17·590	20·47	14·95	15·48	16·10	16 84	13·52	14·53	11·5500
TOTAL	479·82	89·17	141·77	156·20	139·24	2474·56	1670·46	1035·65	619·58	207·44	336·92	426·62	248·15
Average	34·27	6 37	10 13	11·16	9·94	176·75	119·32	73·97	44·25	14·82	24·07	30·47	17·72

TABLE X.

Average monthly amounts of nitrogen as nitrates in drainage waters.

Month	Rainfall	Drainage				Nitrogen parts per million				Nitrogen lb. per acre			
		Gauges				Gauges				Gauges			
		I	II	III	IV	I	II	III	IV	I	II	III	IV
	Inches	6 feet	6 feet	3 feet	3 feet	6 feet	6 feet	3 feet	3 feet	6 feet	6 feet	3 feet	3 feet
June . .	3·46	0·010	0·0002	0·39	0·50	1·74	5·54	2·41	1·90	0·85	0·002	1·68	1·190
July . .	8·10	0·030	1·0400	1·46	1·36	69·25	30·43	12·63	11·90	1·74	2·640	4·35	4·400
August .	11·49	3·280	4·7600	5·47	4·94	44·90	27·95	23·71	19·70	8·20	11·190	15·13	9·480
September .	7·47	2·340	4·2100	3·75	3·03	39·36	31·73	29·61	7·46	4·67	9·810	9·78	2·530
October .	1·38	0 090	0·0900	0·07	0·11	17·41	17·16	4·92	2·53	0·11	0·410	0·17	0·120
November .	0·49	0·001	0 0060	0·02	0·01	4·08	6·44	0·72	0·09	0·01	0·004	0·06	0·002
December .	0·11	..	..	..	..	..	..	..	..	..	..	..	..
January .	0·46	..	..	..	..	..	..	..	..	..	..	..	..
February .	0·44	..	..	..	..	..	..	..	..	..	..	..	..
March .	0·29	..	..	..	..	..	....	..	..	..	..	..	..
April . .	0·08	..	..	..	..	..	..	..	..	..	..	..	..
May . .	0·47	..	..	..	..	..	..	..	..	..	..	..	..

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Nutrients required for Milk Production with Indian Food-stuffs

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NUTRIENTS REQUIRED FOR MILK PRODUCTION WITH INDIAN FOOD-STUFFS.

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(Received for publication on 22nd August, 1925.)

Object of the enquiry.

The serious shortage of milk and its prohibitive price in most of the populous areas of India are facts which have lately become prominent in the public eye. The importance of the milk problem and the need for a more adequate supply are therefore matters which we need not emphasize here. One of the factors on which economical milk production depends is the proper utilization of the available food-stuffs. This fact has been fully realized in Europe and America where experiments have been carried out on a large scale to procure accurate information. The digestibility of foods has been determined, the balancing of rations has been studied, the relative values of proteins have been examined, experiments extending over ten years have been made to ascertain the minimum amount of protein necessary, the food requirement in relation to the amount and quality of the milk has been measured. Finally, from the results of these extensive enquiries, feeding standards have been prepared for practical, economical and adequate feeding of milk cattle.

These results refer to foreign cattle fed on foreign food-stuffs. Our indigenous cattle, and the half-breds, which are serving a most useful purpose temporarily, are peculiar to this country. Some of our food-stuffs too, especially the roughages, differ very considerably from American foods in composition and quality.

The following important question, therefore, presents itself. Can the feeding standards developed in Europe and America be applied to our conditions without any change, or must we introduce modifications and if so how and to what extent? The present enquiry was undertaken to obtain an answer to this question.

On the whole, American conditions approach ours most closely and therefore our comparisons should be made with the American feeding standards. We have selected the data of Haecker[1], Savage[2] and Eckles[3] for this purpose.

Experimental procedures.

1. Eight freshly calved cross-bred cows of various ages and milking capacity were selected. Their rations were adjusted to supply the nutrients necessary for milk production using the Savage allowance of nutrients with somewhat more protein. This standard was chosen for the following reasons :--

(a) The protein allowance is higher than in the other standards. As protein foods are relatively cheap in most parts of India it is not necessary for us to reduce the protein to a minimum.

(b) When commencing the enquiry there was no information available regarding the digestibility of our food-stuffs. As a precaution, therefore, it appeared advisable to feed according to a liberal standard. The ration was altered periodically to correspond with the yield and quality of the milk. The cows were weighed every day. Their milk yields were recorded daily. An aliquot weekly milk sample of each cow was examined for fat and protein content.

2. *Rations.* The cows were given 8 lb. fresh lucerne and silage and hay *ad lib.* as roughage. A weighed excess was provided and the quantities consumed were determined by weighing the residues. The roughages were fed twice a day. The daily consumption by individual cows was remarkably regular, though the proportions of silage and hay eaten differed somewhat for the different animals.

The concentrates used were wet brewery grains, groundnut cake and a mixture consisting of 7 parts wheat bran, 3 parts cotton seed meal and 5 parts grams husk. The adjustment of the ration to the milk yield was made by altering the amounts of cake and mixture.

For calculating rations the digestion coefficients of Henry and Morrison[4] were used in all cases except for the protein of hay and silage. Lower coefficients were used for the protein of these roughages to ensure an ample supply.

3. *Digestion experiments.* As the digestion coefficients used for calculating the rations refer to American food-stuffs there was considerable uncertainty regarding the actual amounts of nutrients digested by our animals. To procure accurate information on this and other points two series of digestion experiments were carried out. The results of these experiments appear to be important and will be considered in detail.

[1] Haecker. *Minnesota Agri. Expt. Stn. Bull.* No. 140. (1919.)
[2] Savage. *New York, Cornell Expt. Stn. Bull.* No. 323.
[3] Eckles. *Missouri Agri. Expt. Stn. Bull.* No 7.
[4] Henry & Morrison. *Feeds and Feeding*, Madison, Wisconsin, 17th edition.

4. *Time Table.* The following time table of the daily routine will make the feeding procedures more clear.

4-30 A.M. Half of the daily concentrate ration fed (soaked overnight).
4-45 A.M. to 6-15 A.M. Milking, recording and sampling.
6-20 A.M. Weighing the cows. Exercise and watering in the yard. Stalls cleaned.
8-0 A.M. Cows tied. Hay fed.
10-30 A.M. Hay residues removed. Cows let out for watering.
11-0 A.M. Cows tied. Silage fed.
2-30 P.M. Silage residues removed. Cows let out to water.
2-45 P.M. Cows tied. Half of the concentrate ration fed (soaked in the morning). Lucerne fed.
3-30 to 4-30 P.M. Milking, recording and sampling.
4-30 P.M. Hay fed.
6-15 P.M. Hay residues removed. Cows let out for watering.
6-30 P.M. Silage fed.
9-0 P.M. Silage residues removed. Cows let out.

A bare paddock with a water trough was provided for the animals. In spite of this rigorous programme, which was found necessary for keeping an accurate record of the food consumption, the cows ate well and maintained a satisfactory milk flow throughout the experimental period of 154 days.

Experimental results.

1. *Food consumption.* To ascertain the amount of food consumed daily moisture determinations of the hay, silage, lucerne and brewery grains and all residues were made every day throughout the experimental period. Regular moisture determinations of composite samples of cake and mixture were also carried out. The consumption of moist food having been determined simultaneously, the consumption of each ingredient expressed as dry matter was calculated from the moisture figures. In Table I of the Appendix is shown the weekly total consumption of each food-stuff expressed in lb. of dry matter. The splendid capacity of cow No. 1 which consumed 35 lb. dry matter a day for a considerable period may be noted. Chemical analyses of all foods were made periodically on composite samples. The averages of the results are shown in Table II of the Appendix. The data contained in these two tables require no comment here. They will be used later for computing the requirements for milk production.

2. *Live weights and Live weight increase.* From the daily weighings the average live weight for each week was found. These figures are given in Table III of the Appendix. It will be noticed that every animal gained in weight during the feeding test. The ration therefore seems to have been liberal. It will appear from further evidence that most of the cows utilized this heavy feed fairly economically. The

significance of the live weight increases will be dealt with more fully later. The average live weight for the entire period has been used for calculating the maintenance requirements of each cow to meet the Haecker and Armsby standards respectively. The maintenance requirements are shown in Table IV of the Appendix.

3. *Milk yields.* The milk and fat percentage for the experimental period are given in Table V of the Appendix. The average fat content of each cow's milk has been calculated from the total milk and the total fat produced during the entire experiment.

4. *Composition of milk.* In all the American standards food is provided not only in accordance with the milk yield but also in proportion to the richness of the milk. Haecker carried out a very large number of milk analyses from which a table of the average fat, protein, and sugar content of milk of different grades was prepared. This table has been used as the basis for the feeding standards of Haecker, Savage and Eckles.

If we are to compare the productive capacities of our cows and our food-stuffs with the corresponding American results, we must first know whether the milk of our cross-bred cows is similar to the milk produced in America. Unfortunately, it was beyond our means to carry out complete analyses, but we procured full data for fat and protein nitrogen and these are the 2 most variable constituents.

The average nitrogen and fat content of the milk of each cow for the entire period is shown in Chart No. 1, in which the continuous line represents the averages

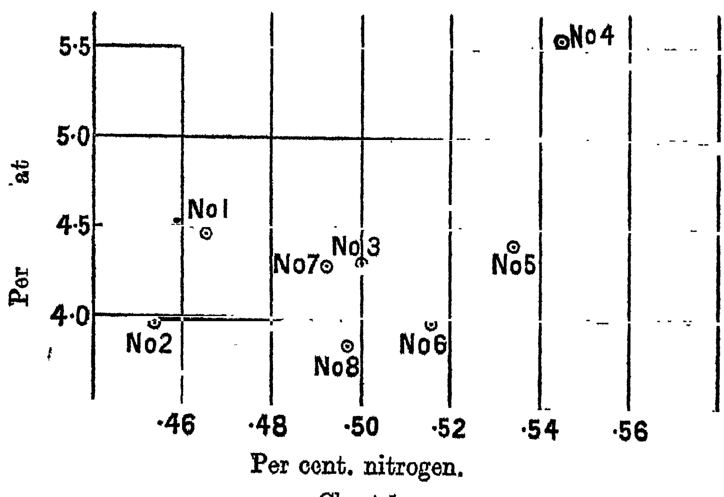

Chart 1.

of Haecker's results. This graph shows that cows 7 and 3 gave milk which was very nearly identical with Haecker's average. Nos. 1, 2, 4 contained decidedly less nitrogen in proportion to their fat content, whilst Nos. 5, 6 and 8 contained distinctly more. The variations are no greater than those obtained by Haecker,

and they are evenly balanced on both sides of the line. Therefore we can conclude that our milk corresponds with Haecker's average in regard to the protein fat ratio.

Chart No. 2 giving the weekly average fat and nitrogen for all the cows further confirms this conclusion. There is apparently some divergence from Haecker's

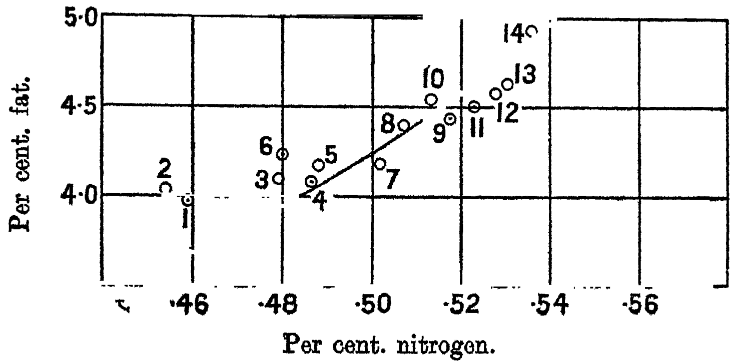

Chart 2.

line for milks low in fat, but this is mainly due to the fact that we have grouped together milks of different grade. The regular increase in fat throughout the 14 consecutive weeks is noteworthy.

Chart No. 3 shows the actual protein fat ratios of the milk samples obtained during the two digestion experiments. These figures will be referred to later. For

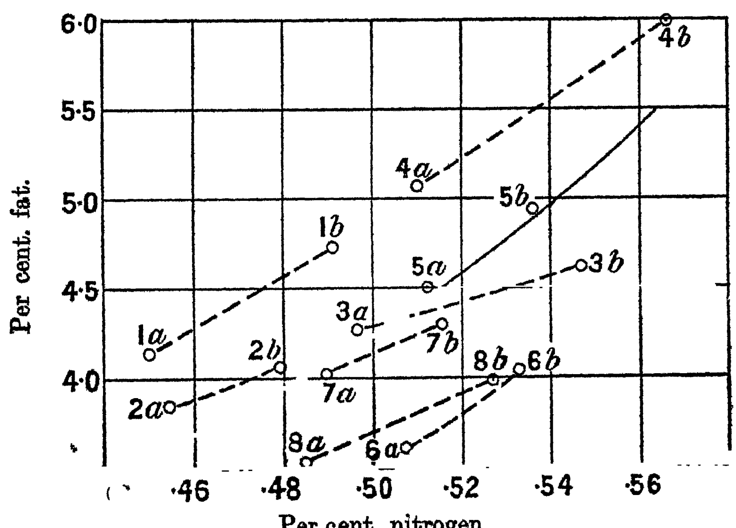

Chart 3.

the present it may be noted that the line joining the two sets of figures for any one

cow is approximately parallel to Haecker's curve, which shows that the normal fat increase accompanying advance in the lactation period is associated with a proportional increase in protein.

5. The digestion experiments and the requirements for milk production will be dealt with separately in the two following sections.

Digestion experiments.

The digestion experiments were carried out at the commencement of the third month (13-8-24 to 26-8-24 for 14 days) and towards the end of the fifth month (14-10-24 to 23-10-24 for 10 days). An inspection of Table I Appendix shows that all the cows were consuming a maximum of dry matter during the first test. An appreciable reduction in the bulk of the ration had taken place when the second digestion experiment was commenced. The results of these two tests are contained in Table I.

Table I.

Digestion coefficients of the mixed ration.

Cow No.	Total organic matter consumed per day	Ratio of food, 1st and 2nd expts.	Digestion Coefficients						Nutritive Ratios, (digested) food
			Protein	Fibre	Nitrogen free extract	Carbohydrates	Fat	Organic matter	
	grm								
1	14920	109·8	61·7	49·1	60·0	56·1	72·5	57·6	5·392
	13583	100·0	60·0	51·2	58·4	55·7	78·3	57·5	6·143
2	11728	117·5	60·3	49·2	50·2	49·8	67·6	51·8	5·175
	9994	100·0	59·2	57·0	54·5	55·5	78·3	56·9	7·299
3	9382	103·6	66·0	59·8	59·7	59·8	72·9	61·4	5·138
	9061	100·0	58·4	57·8	59·4	58·8	74·1	59·6	7·147
4	10961	110·9	60·6	52·2	54·4	53·6	72·2	55·4	5·318
	9885	100·0	57·3	51·8	54·1	53·2	74·1	54·7	6·831
5	11296	111·5	60·1	50·4	54·5	52·9	69·3	51·6	5·483
	10134	100·0	54·6	49·5	51·2	51·6	71·0	53·0	7·102
6	10086	119·5	58·5	54·7	55·1	55·0	68·9	56·1	6·045
	8442	100·0	56·6	56·9	56·3	56·5	69·4	57·1	8·218
7	12390	108·6	59·8	53·3	54·9	51·8	74·9	56·1	5·741
	11413	100·0	63·5	53·4	57·6	56·0	73·0	57·9	5·965
8	11082	106·6	61·6	52·7	54·4	53·7	74·0	56·1	5·130
	10399	100·0	58·5	54·8	58·6	57·2	72·0	58·1	7·210

Digestion in relation to bulk and nutritive ratio of the ration. Armsby[1] has summarized the various factors which affect the digestibility of a ration. Two of these factors concern us here, namely, (*a*) the bulk of the ration, (*b*) its nutritive ratio or the proportion of protein it contains. Armsby's summary shows that digestibility increases as the bulk is reduced, and falls off as the proportion of protein is decreased. It will be noticed in our two tests that with a reduction in bulk, which should improve digestibility, there was a concurrent widening of the nutritive ratio which should reduce digestibility. The actual digestion percentages attained in our two tests are therefore the result of a balance between two opposing factors, one tending to increase, the other tending to decrease digestion. Taking the percentage digestion of organic matter as the best criterion of digestibility, it will be noticed that with the exception of cow No. 2 the digestions attained in the two tests are very similar. The divergences are all trifling and balance one another, three cows giving higher results in the first test, three in the second test, whilst No. 1 gives identical results in the two tests. From this it may be concluded that the opposing factors influencing digestion were fairly well balanced in these two tests. This is an important conclusion. It shows that the average digestion found holds good for the range of bulk changes and alterations in nutritive ratio which occurred during the entire feeding test of 154 days. The averages may therefore be used with confidence for calculating the total digested nutrients. It is not possible to say what changes might have occurred in digestibility if either of these factors had been operative alone. As both the changes in bulk and in nutritive ratio were small it is not likely that either would have produced a marked effect, but the uniformity in the two sets of data is no doubt partly due to the balancing action of the two factors. The exceptional case of cow No. 2 must be considered. We know from the results obtained with the other cows that the food-stuffs remained uniform in character and that the factors of bulk and nutritive ratio cannot account for any appreciable change in digestibility. It must be concluded that this cow was not up to form during the first test and we do not know how long the depression lasted. Whilst the two factors above mentioned have not appreciably affected the digestion of organic matter, it should be observed that the nutritive ratio has exerted a distinct effect upon the digestion of protein and to a less extent on the digestion of fibre. The digestion of protein shows a distinct fall with widening nutritive ratio and the fibre is also generally slightly less perfectly digested.

The digestive capacity of individual cows. The figures point to greater differences between individual cows than to any variations which can be attributed to the factors discussed above. Cow No. 3 appears to have a better digestive capacity than any of the others. She obtained the highest figures for organic matter in both tests, namely, 61·4 per cent. and 59·6 per cent. Nos. 1, 6, 7 and 8 were slightly less efficient, and Nos. 4 and 5 were decidedly inferior. The remarkable parallelism of the 2 tests constitutes a proof that the individual differences are real and

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[1] Armsby. The Nutrition of Farm Animals.

very appreciable. For reasons already given, cow No. 2 is excluded from this discussion. In dealing with the individual cows the bulk of the ration has to be considered from another point of view. A ration which suits a large cow may be too bulky for a smaller animal. The capacity of a cow depends partly upon its size and partly upon the development of its digestive system.

The following figures which are averages of the two digestion experiments are instructive in this connection :—

TABLE II.

Food consumption per 1,000 lb. live weight.

	Cow No 1	Cow No 2	Cow No 3	Cow No 4	Cow No 5	Cow No 6	Cow No 7	Cow No 8
	lb	lb	lb	lb	lb	lb	lb	lb
Average live weight	917	947	895	710	798	834	915	855
Daily food consumption	31.41	23.94	20.33	22.97	23.61	20.12	26.23	23.68
Daily consumption per 1,000 lb. live weight.	34.26	25.28	22.71	32.36	29.59	21.48	28.67	27.69
Average digestion of organic matter	57.60	54.30	60.50	55.10	53.80	56.00	57.00	57.10

Cow No. 3 consumed least food for its body weight and it also showed the highest digestion of organic matter. The high digestion in this case is almost certainly associated with a less voracious appetite. Cow No. 6 also has a low consumption; in this case, however, it is coupled with medium digestion. This cow would have been less efficient in digestion had she consumed 28 or 29 lb. per 1,000 lb. live weight. We may, therefore, expect low efficiency of production from her although the digestion she attained was fairly good. There is no correlation between consumption and digestion with the other cows. Probably the best rough measure of a cow's efficiency for economical milk production is the food consumption capacity per 1,000 lb. live weight, especially if this is combined with satisfactory digestive power. By this standard cow No. 1 must be judged an extremely good animal, while the capacity of all the cows tested is good.

Comparison of computed and actual digestion. The digestion coefficients contained in Henry and Morrison's book are the fullest existing data available for the calculation of rations. The computed digestion has been calculated with the aid of these coefficients. It should be mentioned that digestion experiments carried out at Bangalore using bullocks showed that our oilcake was quite as well digested as Henry and Morrison's figures indicate, bran was very nearly as well digested. Of the roughages, the carbohydrates were quite satisfactorily digested, but the digestion coefficients found for the protein in our hay and silage were distinctly lower than Henry and Morrison's data. Therefore for the protein in silage and hay our lower figures were used. All other coefficients for computing the diges-

tion were taken from Henry and Morrison and applied to our food-stuffs, making due allowance for the actual chemical composition of each food as fed during the digestion experiment. The coefficients used for this computation are given in Table VI-A Appendix. The accompanying table gives the actual and computed digestion coefficient of each ingredient for both experiments.

TABLE III.

Comparison of computed and actual digestion coefficients.

	Protein		Fibre		Nitrogen free extract		Cabo-hydrates		Fat		Digested organic matter	
	1st test	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test	1st test	2nd test
1. Computed .	71·3	71·2	44·0	47·0	61·4	60·5	55·5	55·5	68·7	68·6	58·3	58·1
Actual . .	61·7	60·0	49·1	51·2	60·0	58·4	56·1	55·7	72·5	78·3	57·6	57·5
Difference .	—9·6	—11·2	+4·2	+4·2	—1·4	—2·1	+0·6	+0·2	+3·8	+9·7	—0·7	—0·6
2. Computed .	70 0	69·4	52·3	52·6	59·9	58·7	57·0	56·4	70·0	69·7	59·3	58·3
Actual . .	60·3	59·2	49·2	57·0	50·2	54·5	49·8	55·5	67·6	73·3	51·8	56·9
Difference .	—9·7	—10·2	—3·1	+4·4	—9·7	—4·2	—7·2	—0·9	—2·4	+3·6	—7·5	—1·4
3. Computed .	72·2	70·2	52·1	51·1	59·7	60·1	56 8	56·6	71·4	68·9	59·6	58·7
Actual . .	66·0	58·4	59·8	57·8	59·7	59·4	59·8	58·8	72·9	74·1	61·4	59·6
Difference .	—6·2	—11·8	+7·7	+6·7	0·0	—0·7	+3·0	+2·2	+1·5	+5·2	+1·8	+0·9
4. Computed .	70·3	69·6	50·1	50·7	60·7	60·0	56·8	56·5	69·4	68·3	59·1	58·5
Actual . .	60·6	57·3	52·2	51·8	54·4	54·1	53·6	53·2	72·2	74·1	55·4	54·7
Difference .	—9·7	—12·3	+2·1	+1·1	—6·3	—5·9	—3·2	—3·3	+2·8	+5·8	—3·7	—3·8
5. Computed .	69·5	70·0	50·6	52·2	60 6	60·0	56·8	57·0	73·4	68·4	59·1	58·9
Actual . .	60·1	54·6	50·4	49·5	54·5	51·2	52·9	51·6	69·3	71·0	54·6	53·0
Difference .	—9·4	—15·4	—0·2	—2·7	—6·1	—8·8	—3·9	—5·4	—4·1	+2·6	—4·5	—5·9
6. Computed .	68·5	67·5	51·2	53·9	60·1	58·7	56·7	56·9	68·2	67·5	58·7	58·4
Actual . .	58·5	56·6	54·7	56·9	55·1	56·3	55·0	56·5	68·9	69·4	56·1	57·1
Difference	—10·0	—10·9	+3·5	+3·0	—5·0	—2·4	—1·7	—0·4	+0·7	+1·9	—2·6	—1·3
7. Computed .	67·4	72·0	49·2	53·1	61·1	60·1	56·7	57·5	68·0	69·6	58·8	58·3
Actual . .	59·8	63·5	53·3	53·4	54·9	57·6	54·3	56·0	74·9	73·0	56·1	57·9
Difference .	—7·6	—8·5	+4·1	+0·3	—6·2	—2·5	— ·4	—1·5	+6·9	+3·4	—2·7	—0·4
8. Computed .	70·7	69·5	51 0	50·9	60·7	59·8	57·0	56·4	70·1	68·2	59·5	58·4
Actual . .	61·6	5[illegible]·5	52·7	54·8	54·4	58·6	53·7	57·2	74·0	72·9	56·1	58·1
Difference .	—9·1	—11·0	+1·7	+3·9	—6·3	—1·2	—3·3	+0·8	+3·9	+4·7	—3·4	—0·3
Average .	—8·8	—11·4	+3·3	+2·6	—4·5	—3·5	—1·9	—1·0	+2·2	+4·5	—2·2	—1·6
Average of all .	—10·1		+3·0		—4·0		—1·5		+3·3		—1·9	

In calculating the average difference (last row of figures) the results of the first digestion experiment with cow No. 2 have been excluded for reasons given above. The figures show that the actual digest'on of fibre and fat was consistently better

than the computed digestion. The figures for protein, total carbohydrates, and total organic matter are, however, more significant. The actual protein digestion was without exception decidedly lower than the calculated amount, although full allowance had been made in the computation for the actual protein content of the food, and for the lower digestion of the protein in hay and silage observed in simultaneous bullock tests. The average deficiency amounts to 10·1 per cent., which is a very serious divergence. The digestion of total carbohydrates and total organic matter varied somewhat, but both were in almost all cases lower than the calculated amount, the average deficiency for all the tests being 1·5 per cent. and 1·9 per cent. respectively. Diminished digestion of this kind is found with all heavily fed cattle. Munford[1] has shown the reduction of digestion which occurs when fattening cattle are heavily fed. Eckles[2], and more recently, Perkins and Monroe[3] have shown the same falling off in digestion with dairy cows, when they are put on heavy rations. Eckles went further and showed that the same cows when on a maintenance ration possessed abnormally good digestive power. The fact that we obtained diminished digestion is therefore not significant. It merely corroborates general experience. The important point is to determine how our losses compare with the losses obtained by other workers. For this purpose Eckles'[2] figures can be used. Comparing theoretical with actual digestion the following average differences in digestion coefficients were obtained by Eckles and by us.

TABLE IV.

Difference between actual and computed digestion.

	Dry matter	Protein	Fibre	Nitrogen free extract	Fat
Eckles	—5·3	—8·9	—3·6	—3·7	?
Bangalore	—1·9*	—10·1	+3·3	—4·6	+3·3

* Organic matter.

Applying these figures to the digestion of a normal ration the following results are obtained.

Food ingredients in grm.

	Protein	Fibre	Nitrogen free extract	Fat	Organic matter	Loss of organic matter	Per cent. losses.
Ration	1,500	3,500	5,900	310	11,240	..	.
Computed digestion	1,050	1,575	3,600	231	6,456	..	.
Bangalore actual	900	1,080	3,363	216	6,189	267	4·1
Eckles actual	916	1,449	3,380	231	5,976	480	7·4

[1] Munford and others. *Illinois Agri. Expt. Stn. Bull.* No. 172 (1914).
[2] Eckles. *Missouri Agri. Expt. Stn. Bull.* No. 7.
[3] Perkins & Monroe. *Ohio Expt. Stn. Bull.* No. 376 (1924).

There is, no doubt, from these figures that the actual digested nutrients and net energy of the ration in Eckles' experiments fell considerably below the anticipated computed amounts. Our results agree with his in the low values obtained for protein digestion, in which the greatest divergence from the computed amounts occurs. In other respects, especially in the significant figures for total organic matter, our results are much more favourable, and show that the net energy of the rations actually digested by our cows is not very seriously reduced below the computed amount. The real difference between our results and those of Eckles lies in the digestion of crude fibre. There are two possible explanations for the higher efficiency obtained by us. Firstly, it may be argued that the bulk of the rations fed to our animals was smaller. From what has been said above, this would account for better digestion, but the argument does not hold in the case of cow No. 1, which was consuming the splendid total of 35 lb. of dry matter per day during the first digestion experiment. Nos. 7 and 8 were also consuming very heavy rations, and the digestion attained by these cows is up to or above our average, which has actually been lowered by some of the cows consuming less food. It is therefore not possible to account for our favourable results in this way. Secondly, the result may be attributed to the fact that our ration provided a high proportion of protein which, as stated above, increases the digestibility of a ration and especially the digestibility of fibre. In this connection, the results obtained recently by Perkins and Monroe are instructive for comparison. With wide and narrow nutritive ratios respectively, the following differences between computed and actual digestion were obtained by Perkins and Monroe and by us.

TABLE V.

The effect of the nutritive ratio upon the difference between actual and computed digestion.

	Protein	Fibre	Net energy fat	Organic matter
Perkins and Munroe—				
Wide nutritive ratio 1 : 9	—7·6	—7·7	—3·2	..
Narrow nutritive ratio 1 : 4	—4·6	—5·8	—0·7	..
Bangalore—				
Wide nutritive ratio 1 : 6·99	—11·4	+2·6	+3·5	—1·6
Narrow nutritive ratio 1 : 5·42	—8·8	+3·3	+3·5	—2·2

With respect to protein and fibre our results run parallel with Perkins and Monroe, both being better with a narrow ratio, though absolutely our protein is worse digested, and our fibre is very much better digested. For nitrogen-free extract and organic matter our results are different. We find a slightly lower digestion with the narrower ratio. The differences are small, however, and, as far as they can be considered significant, they must be attributed to the fact that in our experiment two opposing factors were operating. It would seem that an alteration in the nutritive ratio has more effect on the digestion of protein and fibre, whilst the bulk of the ration especially influences the digestion of organic matter. The most important point in these figures is that our fibre digestion was superior to that obtained by Perkins and Monroe even when their ration had a narrower nutritive ratio than any we employed. We conclude from these results that our cows possess a definitely better digestive capacity for fibre, and consequently also for organic matter, and that the superiority is not completely accounted for by excess of protein in our rations.

Nutrients and net energy required for milk production.

To ascertain the requirements for milk production the following procedure is employed. In the first place the total digested nutrients are determined. From this total is deducted the amount required for other purposes, namely for maintenance and for increase in live weight. The balance left is the amount available for milk production. The calculation of total nutrients digested is based on the total food consumption (Table I of the Appendix). The figures can be dealt with in two ways. These are (*a*) by the use of our digestion data, in which case the chemical analyses of Table II Appendix become applicable, or (*b*) by employing Henry and Morrison's digestion coefficients and Armsby's net energy values. The first process takes account of the chemical composition of the food-stuffs actually employed and of the digestive capacity of each individual. The figures for actual digestion so obtained rests on two sets of digestion experiments which gave satisfactorily concordant results. They must, therefore, be considered reliable.

The second process assumes that the food-stuffs were of average composition and digestibility. It is true, we happen to know in this particular instance, that the digestibility of the protein in our hay and silage was somewhat lower than Henry and Morrison's figure, but this information is not always available. Therefore, until we possess tables of digestion coefficients of Indian food-stuffs, and while we have to employ American coefficients, we must use them in the way they are intended to be used, introducing what corrections we can afterwards. As two alternative methods are in common use for expressing the nutritive values of foods, namely, in terms of total digested nutrients and as net energy, we will give our results in both forms in the succeeding tables. It should be noted that the computed digested nutrients and net energy given in the accompanying table VI have been calculated by using the American coefficients in the normal manner. (The coefficients

employed are given in Table VI-B of Appendix.) The computed figures of Table V do not quite agree with the computed values of this table, because in the former due allowance was made for the lower digestibility of the hay and silage proteins. Further, Table V refers only to the rations consumed during the digestion experiments, while Table VI gives the nutrients digested during the entire feeding test of 154 days.

Table VI.

Comparison of computed and actual digested nutrients.

	Digested crude protein		Digested organic matter		Digested nutrients		Net energy	
	lb.	Actual as per cent. of computed	lb.	Actual as per cent. of computed	lb.	Actual as per cent. of computed	Therms	Actual as per cent. of computed
No. 1. Computed	549·1		2760·5		2967·9		2625·7	
Actual	420·7	76·62	2630·0	95·27	2803·0	94·44	2502·0	95·20
Difference	128·4		130·5		164·9		123·7	
No. 2. Computed	406·9		2202·6		2355·5		2090·0	
Actual	295·8	72·70	1970·3	89·45	2084·1	88·48	1870·0	89·47
Difference	111·1		232·3		271·4		220·0	
No. 3. Computed	368·5		1900·6		2035·1		1805·9	
Actual	279·6	75·88	1867·7	98·27	1971·5	96·88	1775·0	98·29
Difference	88·9		32·9		63·6		30·9	
No. 4. Computed	405·3		2107·8		2259·5		2002·2	
Actual	300·1	74·04	1892·5	89·78	2010·1	88·96	1797·0	89·75
Difference	105·2		215·3		249·4		205·2	
No. 5. Computed	405·5		2119·3		2271·2		2011·8	
Actual	294·1	72·53	1862·2	87·87	1975·2	86·97	1768·0	87·88
Difference	111·4		257·1		296·0		243·8	
No. 6. Computed	337·6		1888·7		2017·1		1774·2	
Actual	240·1	71·12	1752·5	92·79	1845·2	91·69	1646·0	92·77
Difference	97·5		136·2		171·9		128·2	
No. 7. Computed	456·0		2411·8		2584·2		2286·3	
Actual	354·2	77·67	2253·8	93·45	2390·5	92·51	2137·0	93·49
Difference	101·8		158·0		193·7		149·3	
No. 8. Computed	418·8		2202·8		2359·1		2090·8	
Actual	314·8	75·17	2056·0	93·12	2177·8	92·31	1951·0	93·31
Difference	104·0		146·8		181·3		139·8	
Average		74·5		92·5		91·5		92·5

Note.—The American coefficients used for determining computed digested nutrients and net energy are given in Table VI-B Appendix.

Looking first at the figures for digested protein, it will be seen that there is in every case a considerable discrepancy between the computed and actual amounts digested, which when shown as a percentage is remarkably uniform, the amount actually digested being about 75 per cent. of the computed quantity. Part of this difference can be accounted for by the fact that the hay and silage used do not provide an average amount of digestible protein but this accounts only for about 30 lb. The remaining deficit is undoubtedly due to lowering of digestive capacity brought about by heavy feeding—a point which has already been referred to. It may be noted here that in the digestion experiment data of Table III, in which the low digestibility of protein from the hay and silage was allowed for, the actual digestion was found to be 10 per cent. below the computed quantity.

In the case of digested organic matter, total nutrients, and net energy there is a much greater range of variation between the computed and actual values. This is due to the observed differences in the digestive capacities of the individual cows. The computed figures are calculated on the assumption that all the cows have the same average digestive capacity, whilst the actual figures take account of individual differences. For practical feeding purposes it must be admitted that differences in digestive capacity cannot be considered, although the figures in this table show that they may be appreciable. The average results are, however, of very great practical importance. They show that our cows actually obtained 91·5 per cent. of the computed nutrients and 92·5 per cent. of the computed net energy. These figures can be compared directly with Eckles' figures in *Research Bulletin* No. 7 on Nutrients required for milk production. Eckles determined the actual digestion effected by 8 cows fed on a heavy ration, and found in every case that the actual digestion was distinctly lower than the computed amount. He then determined the computed and actual net energy of the food for each cow for the entire period. From his digestion data it is difficult to understand how it happens that the actual net energy consumed by two of the cows is greater than the computed amount. (Compare Eckles' *Res. Bull.* 7, Tables 27 and 28). There is no reference made to these remarkable figures in the text. For the remaining six cows the actual net energy is lower than the computed amount, as was to be expected from the digestion data. The results for these six cows are very similar and give an average for the actual net energy which is 93·14 per cent. of the computed amount. Our average of 92·5 per cent., seeing that it is obtained with a relatively poor hay in the ration, constitutes a remarkably good performance and shows that the cows tested by us possess excellent digestive powers.

To arrive at figures for milk production requirements we have now to deduct from the digested nutrients shown in Table VII the quantities used for maintenance and live weight increase. The estimation of the maintenance requirements in protein, nutrients, and net energy are based on the average live weight of each animal for the entire period. They are calculated from the standards given by Haecker and Armsby according to the surface law. The maintenance requirements

so obtained are given in Table IV in the Appendix. The significance of the live weight increases, shown in Table III Appendix, has to be considered next. It is possible to correlate these increases with food consumption in the following manner. If we deduct from the computed amount of food digested the amounts required for maintenance and for milk production we should obtain a positive balance to account for the increase in live weight. The maintenance requirements are contained in Table IV in the Appendix. For estimating the nutrients required for milk production, the averages of Haecker's (1) and Savage's (2) figures have been used. These calculations lead to the following results.

TABLE VII.

Computed nutrients and net energy available for live weight increases.

Cow No.	Computed nutrients available for live weight increase			Actual increase in live weight lb.	Order of live weight increase		
	Protein lb.	Nutrients lb.	Net energy therms		Actual	According to computed nutrients	According to computed net energy
1	+106·8	—229·8	—157·8	37·1	6	8	8
2	+109·8	+38·8	+214·0	30·3	8	3	2
3	+98·8	—116·0	+51·5	42·7	5	7	6
4	+104·0	—68·0	—65·0	32·4	7	6	7
5	+107·0	—31·1	+106·5	60·8	2	4	4
6	+105·0	+104·0	+248·4	77·5	1	2	1
7	+103·0	—43·0	+75·9	43·5	4	5	5
8	+113·0	+133·4	+211·0	57·0	3	1	3

According to these figures some of the cows should have lost weight. This result may be due to slight overestimates for the requirements for milk production, to slight underestimates of the available nutrients, or to both causes. In any case, the estimates for all the cows must err in the same direction and very nearly to the same extent. Therefore, the balances whether positive or negative should show the order of live weight increase. With the exception of cow No. 2, which will be excluded for the present, the figures show a close agreement between the order of live weight increase and the balance of nutrients and net energy. We find that the three cows which gained most (Nos. 5, 6 and 8) did actually receive the greatest computed excess of nutrients and net energy, whilst Nos. 1, 3 and 4 which made smaller gains also received a lower margin of nutrients and net energy for the purpose. Cow No. 2, it must be admitted, is entirely out of place. A reference to the digestion data shows that there is doubt about her digestive capacity. It may have been very low for most of the time and hence the computed figures do not give a fair estimate in her case. On the whole, there is a distinct correlation between the observed live weight increases and the computed excess of nutrients fed. It is

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probable that the three cows which made the highest gains did actually put on some flesh or fat. Judging from further tests which are in progress here, we believe that the live weight increases observed in the experiments under discussion were at least partly due to distension of the digestive tract through heavy feeding. In our calculations we have ignored the live weight increases, and, consequently, any nutrients used for this purpose are included in the food cost of milk production. The nutrients available for milk production after making the necessary deduction for maintenance (and ignoring changes in live weight) are shown in the accompanying table.

TABLE VIII.

Nutrients available for milk production. Comparison of computed and actual results.

	Crude Protein		Total Nutrients		Net Energy	
	lb.	Actual as per cent. of computed	lb.	Actual as per cent. of computed	Therms	Actual as per cent. of computed
No. 1. Computed	450·8		1820·2		1756·7	
Actual	322·4	71·53	1655·3	90·94	1633·0	92·96
Difference	128·4		164·9		123·7	
No. 2. Computed	303·8		1170·8		1193·3	
Actual	192·7	63·53	899·4	76·82	973·3	81·56
Difference	111·1		271·4		220·0	
No. 3. Computed	271·8		900·0		946·5	
Actual	182·9	67·29	836·4	92·93	916·6	96·84
Difference	88·9		63·6		29·9	
No. 4. Computed	329 0		1290·0		1268·0	
Actual	223 8	68·02	1040·6	80·67	1062·8	83·82
Difference	105 2		249·4		205 2	
No. 5. Computed	319·1		1218·9		1214·9	
Actual	207·7	65·09	922·9	75·71	971·1	79·93
Difference	111·4		296·0		243·8	
No. 6. Computed	248·3		941·0		959·5	
Actual	150·8	60·73	769·1	81·75	831·3	86·64
Difference	97·5		171·9		128·2	
No. 7. Computed	357·4		1434·2		1415·6	
Actual	255·6	72·08	1240 5	86·40	1266·3	89·45
Difference	101·8		193·7		149·3	
No. 8. Computed	326·8		1361·4		1259·7	
Actual	222·8	68·18	1080·1	79·39	1119·9	88·90
Difference	104·0		281·3		139·8	
Average		67·05		83·09		87·38

It will be noticed in this table that while the difference between the computed and actual quantities is exactly the same as in Table VI, the quantities themselves have been reduced by the amounts required for maintenance. Hence the proportion which the actuals bear to the computed figures are much lower in this table than in the last, and the differences between the individual cows, which were relatively small in Table VI, are here greatly exaggerated. For instance, the actual protein in table VI varied between 72 and 76 per cent. of the computed, now it ranges from 62 to 72 per cent. The same holds good for the total nutrients and net energy. The alteration is naturally most marked with the cows which gave least milk, *i.e.*, in those cases in which the amount of nutrients available for milk production is low (No. 6); the alteration is least marked for those cows which consumed an excess of nutrients (Nos. 1 and 7) or possessed a high digestive power (No. 3). We have to conclude from tables VI and VIII that the computed values for digested and available protein are not reliable. The computed values for digested nutrients are not so far out, but when deductions are made for maintenance, the error is exaggerated and the figures become less reliable, this is especially the case when the milk yield is low.

Nutrients required per lb. of milk.

To compare the utilization of food for milk production the figures of Table VIII must be considered in conjunction with the amount of milk produced. The efficiency with which food is utilized for this purpose is best expressed by the amounts of proteins, nutrients, and net energy utilized in the production of one lb. of milk. The calculation of these amounts is shown in the Appendix Table VII. The results are summarized in the accompanying table, which also includes results obtained by other workers.

TABLE IX.

Nutrients used for the production of 1 lb. of milk.

Cow	Milk yield lb.	Average per cent. fat	Live weight increase lb.	PROTEIN IN LB.				TOTAL NUTRIENTS IN LB.				NET ENERGY IN THERMS		
				AMERICAN		BANGALORE		AMERICAN		BANGALORE		AMERICAN	BANGALORE	
				Haecker	Savage	Computed	Actual	Haecker	Savage	Computed	Actual	Eckles	Computed	Actual
No. 1 . . .	5461 2	4·49	37·1	·057	·069	·083	·059	·372	·379	·333	·303	35	·322	·299
No. 2 . . .	3264 5	3·95	30·3	054	·065	·093	·059	·343	·350	·359	·276	·30	·366	·293
No. 3 . .	2887 3	4·11	42·7	054	·066	·094	·063	·348	356	·312	·290	31	·328	·318
No. 4 . . .	3331·8	5·28	32·4	·061	074	099	·067	·404	411	·387	·312	40	·381	·319
No. 5 . . .	3463 8	4·25	60·8	·056	·067	·092	·060	·357	·365	·352	·266	·32	·351	·280
No. 6 . . .	2452·0	3·89	77·5	·053	·064	·101	·062	·337	346	·384	·314	·29	·391	·280
No. 7 . . .	4059·8	4·29	43·5	·056	·068	·083	·063	·360	·368	·353	·306	·33	·349	·312
No. 8 . . .	3745·3	3·71	57·0	·051	·063	·087	·060	·325	·331	·363	·288	·28	·337	·299
Average .	..	..	..	..	..	..	..	·356	·363	·355	..	·323	·353	..

The American figures in this table have been obtained by computation exactly as our computed figures and are therefore comparable with them. Our actual figures cannot be compared with the American results. They are inserted here mainly to show the great difference between actual and computed requirements. The figures for actual requirements will be considered later. According to the computed figures, we fed very much more protein, and did not get an equivalent return in milk. It is true that our computed protein should be slightly reduced to make allowance for the difference between American and Indian food-stuffs (see digestion results), but this reduction would make only a trifling difference to our computed figures, which would still remain very much higher than the American figures. It is possible that our high protein ration resulted in greater milk secretion —the point has not been investigated—but it is quite clear that if there was an increase in milk yield it was not proportional to the excess of protein fed. It has already been stated that when compounding rations we purposely assumed low digestion co-efficients to avoid underfeeding. Computing with the ordinary digestion co-efficients, therefore, we find our cows received decidedly more protein than the Savage standard demands. This excess has to be paid for by milk production. Therefore, it happens that the most extravagant users of computed protein were the cows which gave low milk yields, whilst the high milkers were least extravagant. The following figures bring out these facts clearly.

TABLE X.

Protein for milk production.

PROTEIN FOR MILK PRODUCTION		Excess lb.	Excess per cent.	REQUIRED PER LB. MILK		Difference	Order of milk yield	Total milk yield
Computed lb.	Required by Savage standard lb.			Our computed value	Savage standard			
1	2	3	4	5	6	7	8	9
450	377	73	20	·083	·069	·014	1st	5461
304	212	92	45	·093	·065	·028	6th	3264
272	191	81	45	·094	·066	·028	7th	2887
329	247	82	33	·099	·074	·025	5th	3332
319	232	87	35	·092	·067	·025	4th	3464
248	157	91	60	·101	·064	·037	8th	2452
357	280	77	20	·088	·068	·020	2nd	4060
327	236	91	38	·087	·063	·024	3rd	3745

The excess of computed protein over that required by the standard is much the same for all the cows, while the per cent. excess is very different. It will be observed

that the difference between computed and Savage requirements (Column 7) does not run parallel with the per cent. excess shown in the 4th column but is proportional to the milk yield. The error is therefore mainly governed by the milk yield. Further evidence on the excess of protein fed to our cows is obtained by a study of the urinary nitrogen excretion, which was determined during the two digestion experiments. The results obtained are shown in the accompanying table.

TABLE XI.

Ratio of milk nitrogen to urinary nitrogen.

Cow No.	Order of milk yield	Test	Average daily milk yield during test lb.	Average daily nitrogen content of milk grm.	Average daily nitrogen excretion in urine grm.	Ratio of Milk N. to Urinary N.
1	1	1st test . .	38·4	78·87	135·84	1 : 1·723
		2nd test . .	30·3	69·63	117·50	1 : 1·688
2	6	1st test . .	23·9	49·33	118·30	1 : 2·398
		2nd test . .	15·3	35·05	94·54	1 : 2·698
3	7	1st test . .	18·7	42·02	97·36	1 : 2·317
		2nd test . .	15·0	37·29	103·90	1 : 2·716
4	5	1st test . .	24·1	55·85	107·20	1 : 1·821
		2nd test . .	17·7	46·02	82·30	1 : 1·788
5	4	1st test . .	25·2	58·66	98·31	1 : 1·676
		2nd test . .	17·7	43·17	74·05	1 : 1·715
6	8	1st test . .	17·3	39·32	88·10	1 : 2·241
		2nd test . .	12·1	29·45	63·26	1 : 2·148
7	2	1st test . .	29·1	64·73	106·95	1 : 1·652
		2nd test . .	24·0	56·92	100·40	1 : 1·764
8	3	1st test . .	27·0	59·55	103·96	1 : 1·746
		2nd test . .	20·2	48·35	79·00	1 : 1·634

These figures are not based on any computations. They represent the actual amounts of nitrogen contained in the milk and urine as determined in careful digestion experiments, and the evidence they provide is conclusive. The urinary nitrogen is a direct measure of the amount of protein supplied in excess of that converted into milk protein. It is seen again, and more convincingly here, that the excess

of protein fed becomes most marked in the case of the cows which gave a low milk yield. The urinary nitrogen of the 3 low yielders, Nos. 2, 3 and 6, is relatively very great. With each of these cows the ratio Milk N. to Urinary N. is greater than 2. With the other cows, the ratio ranges between 1·6 and 1·8. These ratios have now to be compared with figures obtained by other workers. Haecker's[1] results which were obtained with rations low in protein may be taken first. He found that with a computed digestion of 1·845 lb. protein the milk contained ·793 lb. From Eckles' actual digestion determinations we may conclude that Haecker's computed digestion of 1·845 lb. corresponds to 1·580 lb. of actually digested protein. As ·793 lb. of this is returned in the milk, ·787 lb. must have been voided in the urine. That is to say, Haecker's Ratio of Milk N. to Urinary N. obtained with a low but sufficient supply of protein is about 1·0. Figures from Eckles in Bulletin No. 4, University of Missouri, give ratios below unity, namely, ·84 and ·80. Jordon and Jenter's[2] figures during 3 periods, in which the protein supplied was first normal, then somewhat low, and finally normal again, yield the following ratios, 1·51 ; 1·20 ; 1·46. A comparison of these ratios proves beyond doubt that our cows actually received a considerable excess of protein, a fact which we were led to believe from the computed figures.

Turning now to the computed total nutrients used for milk production, we find that the Bangalore average is exactly equal to the average of Haecker's figures, and somewhat lower than Savage's figures. At the same time there is no doubt that the hay used by us was less digestible than the hay employed in the American experiments. The question, therefore, has to be asked how our cows attained their high efficiency. In this connection a recent statistical examination of the Savage standard by Meigs and Converse[3] is worth referring to. Tests carried out by these workers with an entire herd indicated that the Savage standard was just sufficient. Our cows have apparently produced milk at a lower cost, namely, that of the Haecker standard. There are two possible explanations which we have to offer for this high efficiency. Firstly, it may be due to the higher proportion of proteins in the total digested nutrients. It seems a reasonable supposition that the nature of the digested nutrients must affect their value for milk production not only directly but also indirectly by their influence on the work of digestion. Our ration provided considerably more protein than the Haecker standard, and probably also distinctly more than the Savage standard. If extra protein in the total nutrients enhances their productive value, as it is also almost certain to increase the net energy value of a ration, then we have a possible explanation for the efficiency attained. Secondly, efficiency may be gained by better actual digestion, which means more actual nutrients for a given quantity of computed nutrients. The digestion experiments discussed above showed unmistakable evidence of better digestion on the part of

[1] Haecker. *Minnesota Agri. Expt. Stn. Bull.* No. 140 (1919).
[2] Jordan & Jenter. *New York Agri. Expt. Stn. Bull.* No. 132 (1897).
[3] Meigs & Converse. *Jour. of Dairy Science*, Vol. 8, p. 177 (1925).

our cows. These digestion results help us now to account for the high efficiency observed in the utilization of computed nutrients. It is possible that both these factors, a high protein ration and a better digestive capacity contributed to our favourable result. In the utilization of computed net energy our average requirement per lb. of milk was distinctly higher than Eckles' figure. But according to Meigs and Converse (*loc. cit.*) the Eckles standard of net energy for milk production is not quite sufficient for the maintenance of body weight. As our cows maintained their body weights, they should require according to Meigs and Converse somewhat more net energy than that allowed by Eckles. Therefore our figures, though they are derived from a relatively small experiment, agree with the findings of the most recent investigation on this subject.

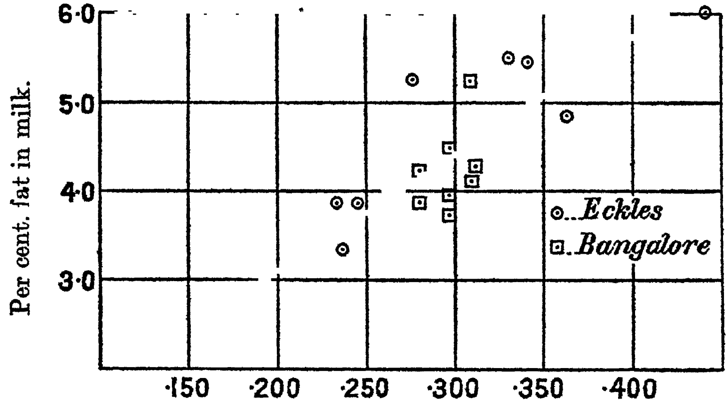
Finally, the figures for actual protein, nutrients and net energy requirements for milk production have to be considered. The outstanding fact, which has already been emphasized by other workers, is that, owing to a diminution of digestion, the actual requirements of digested food are decidedly lower than the computed values. The differences are very considerable and it must be admitted that an improved procedure for computation is desirable. Such a procedure will only be found after much experimental work has been done and, unitl we have this procedure, the actual requirement figures cannot be used for rationing. We must adhere to computed values. That the question of food requirement for milk production has not been cleared up by any means yet, is made evident by examining the data obtained for the actual net energy requirements for milk production. Figures for our 8 cows are contained in Table IX. Eckles gives figures for 8 cows in Bulletin No. 7. These two sets of figures are collected together in the accompanying table.

TABLE XII.

Actual net requirements of net energy per lb. milk produced.

Cow No.	Eckles		Cow No.	Bangalore	
	Per cent. fat in milk	Net energy required per lb. milk		Per cent. fat in milk	Net energy required per lb. milk
206	3·40	·235	1	4·49	·299
304	3·85	·233	2	3·95	·298
400	3·89	·243	3	4·11	·318
43	4·88	·364	4	5·28	·319
62	5·31	·276	5	4·25	·280
4	5·50	·342	6	3·89	·280
27	5·51	·332	7	4 29	·312
63	6 09	·442	8	3·71	·299

It is difficult to see the significance of these figures as they stand, but when put in graphic form (Chart 4) their meaning becomes clear. The graph shows that the



Therms net energy required per lb. of milk.

Chart 4.

net energy requirement per lb. of milk increases with the fat content of the milk. The continuous line on the graph represents approximately the average requirement. Eckles in his bulletin came to this conclusion tentatively, but his figures were scarcely sufficient to enable him to construct a convincing graph. In the present graph it will be seen that our results fill up the gap in Eckles data, they amplify his results, and corroborate them. It remains now to compare the net energy required per lb. milk with the energy content of the milk produced. The figures in the second column are obtained from Chart 4 above. The figures of column 3 are calculated from the average composition of milk of these grades.

TABLE XIII.

Net energy requirement compared with the energy content of milk produced.

Per cent. fat of milk	Net energy required per lb. milk	Energy content per lb milk.
3·0	·159	·260
4·0	·252	·312
5·0	·349	·363
6·0	·420	·414

Eckles showed that the net energy required for the production of average milk is actually less than the energy content of the milk produced. He concluded that the conception of net energy with respect to milk production requires investigation. Our data confirm these conclusions, and the 2 sets of figures, combined together, amplify one another to produce a satisfactory graph.

Energy cost of fat production.

Where milk is used for butter or *ghi* manufacture, the question of requirements for fat production becomes important. In the accompanying table the cows have been arranged in the order of the average fat content of their milk. The figures for fat percentage and total fat yield have been obtained from Table V in the Appendix.

TABLE XIV.

Energy cost of milk fat production.

Cow No.	Per cent. fat in milk	Total fat	Total energy of digested ration. Therms	Total energy per lb. fat. Therms	Available energy (Maintenance deducted). Therms	Available energy per lb. fat. Therms
4	5·28	175·35	1797	10·25	1062·8	6·06
1	4·49	245·83	2502·	10·18	1633·0	6·63
7	4·29	165·73	2137·0	12·89	1266·3	7·64
5	4·25	145·61	1768 0	12·13	971·1	6·67
3	4·11	118·95	1775·0	14·92	916·6	7·71
2	3·95	125·72	1870	14 87	973·3	7·74
6	3·89	95·74	1646	17·19	831·3	8·68
8	3·71	138·95	1951	14·04	1119·9	8·06

The last column of table XIV shows that the utilization of available food energy for butter fat production is very nearly proportional to the fat percentage in the milk. One pound of fat in rich milk is produced with less food energy expenditure than 1 lb. of fat in poorer milk. This result is due to the fact that milk rich in fat contains also proportionately more fat than protein and sugar. Therefore a greater proportion of the food goes to the production of fat. From the economic point of view we have to consider the total food energy expenditure and not the expenditure of available energy.

Column 3 shows that the total food consumption per lb. of fat depends not only on the fat percentage but on the total daily fat yield. Column 3 is the real measure of economy in fat production. It shows that cow No. 1 is quite as efficient as No. 4, and No. 8 is better than No. 3.

Summary.

1. Two sets of digestion experiments, in which two factors affecting digestibility were operating, showed that the actual digestion of organic matter was very nearly uniform for each cow throughout the feeding trial. Appreciable differences between individual cows were noted.

2. A comparison of the computed digestion with the actual results obtained showed that the actual digestion of protein was decidedly less, of the fibre and fat distinctly more and of the organic matter slightly less than the computed amounts.

3. Comparing the depressions of digestion obtained at Bangalore with the depression noted in American experiments it was found that our protein digestion was more depressed, while our organic matter digestion was less depressed. The latter is a favourable result. which can only be partly accounted for by the high protein content of our ration. We are led to the conclusion that our cows possess a slightly better digestive capacity for organic matter, and the difference is mainly due to higher digestion of fibre.

4. Computed requirements for milk production. Our average computed requirement of digestible protein is ·092 lb. per lb. of milk. Savage's average is ·067 lb. Our computed figure, however, is not strictly comparable with Savage's, because (*a*) our roughages contain less than the average amount of digestible protein, (*b*) our cows digest slightly less protein, even when allowance is made for the low digestibility of our roughage. Therefore the excess of protein actually digested and utilized per lb. of milk is less than the difference between these two figures. That we fed a considerable excess of protein is shown by the Urinary N. to Milk N. ratios. Our average requirement of computed total nutrients is found to be equal to Haecker's figure. From evidence adduced, this is seen to be a very economical use of total computed nutrients. The efficiency attained by our cows is attributed partly to the large proportion of protein in our total nutrients, and partly to the better digestion attained by our cows.

5. The actual requirements for milk production are in every case much lower than the computed figures. There is at present no procedure for making computations which agree closely with actual results.

6. In applying existing digestion co-efficients to the computation of rations in India, we find that the results obtained are not strictly comparable with American data. For rations similar to those used by us (and these rations imply an abundance of protein foods), the American digestion co-efficients are applicable if an excess of protein is fed and total nutrients are provided according to the Haecker's standard. At present it is impossible to say what the result would be with less protein than the amount used by us.

7. The conception of net energy with respect to milk production requires further investigation. The data obtained by Eckles showed that the net energy required for the production of milk is less than the energy content of the milk produced. Our figures corroborate and amplify Eckles' data.

Acknowledgments. We are greatly indebted and express our thanks to Mr. Smith Imperial Dairy Expert, for the facilities he afforded us in carrying out this enquiry The animals, the stalls and the foods were provided by him. We have also to thank the Physiological Chemist's staff who carried out the numerous analyses.

APPENDIX.

TABLE I.

Total food consumption (dry matter in lb.).

Cow No.	Date	Hay	Silage	Lucerne	Grain mixture	Groundnut cake	Brewery grain
1	From 23-VI-24 to 14-VII-24 .	222·5	156·2	25·3	221·6	84·8	74·7
	From 21-VII-24 to 11-VIII-24	218·4	153·2	32·0	378·2	76·6	73·0
	From 18-VIII-24 to 8-IX-24 .	214·1	190·3	31·6	411·4	60·8	71·7
	From 15-IX-24 to 6-X-24 .	216·3	201·6	20·7	335·3	57·7	75·4
	From 12-X-24 to 3-XI-24 .	208·5	212·5	32·3	302·8	50·2	73·8
	From 10-XI-24 to 17-XI-24 .	110·0	93·3	15·3	117·9	27·8	36·4
		1189·8	1007·1	166·2	1808·2	363·9	405·0
2	From 23-VI-24 to 14-VII-24 .	212·5	212·6	24·1	149·7	75·4	74·7
	From 21-VII-24 to 11-VIII-24	218·7	217·8	16·1	121·5	74·8	73·0
	From 18-VIII-24 to 8-IX-24 .	198·4	272·9	9·2	147·4	68·6	71·7
	From 15-IX-24 to 6-X-24 .	176·4	273·5	9·7	130·6	51·5	75·4
	From 12-X-24 to 3-XI-24 .	181·6	252·8	9·2	76·0	50·3	73·8
	From 10-XI-24 to 17-XI-24 .	112·0	93·3	4·4	37·0	25·0	36·4
		1094·6	1322·9	72·7	662·2	345·6	405·0
3	From 23-VI-24 to 14-VII-24 .	168·3	168·4	25·2	149·7	71·8	74·7
	From 21-VII-24 to 11-VIII-24 .	194·6	200·5	29·0	87·0	63·8	73·0
	From 18-VIII-24 to 8-IX-24 .	169·5	238·4	31·5	76·8	65·5	71·7
	From 15-IX-24 to 6-X-24 .	132·4	147·3	28·7	88·2	42·9	75·4
	From 12-X-24 to 3-XI-24 .	126·1	209·8	32·3	100·0	37·6	73·8
	From 10-XI-24 to 17-XI-24 .	68·4	108·1	15·3	49·3	19·8	36·4
		859·3	1072·5	162·1	551·0	301·4	405·0
4	From 23-VI-24 to 14-VII-24 .	122·0	186·0	25·3	149·7	75·4	74·7
	From 21-VII-24 to 11-VIII-24 .	147·3	225·4	32·0	151·5	66·5	73·0
	From 18-VIII-24 to 8-IX-24 .	156·0	250·7	31·5	153·5	62·4	71·7
	From 15-IX-24 to 6-X-24 .	149·7	249·5	29·7	124·4	62·7	75·4
	From 12-X-24 to 3-XI-24 .	138·7	244·2	32·8	123·2	38·5	73·8
	From 10-XI-24 to 17-XI-24 .	69·3	112·5	15·3	61·6	18·8	36·4
		783·0	1268·3	166·1	763·9	324·3	405·0

TABLE I—*concld.*

Total food consumption (dry matter in lb.)—concld.

Cow No.	Date	Hay	Silage	Lucerne	Grain mixture	Groundnut cake	Brewery grain
5	From 23-VI-24 to 14-VII-24	122·0	198·3	25·3	205·0	75·4	74·7
	From 21-VII-24 to 11-VIII-24	155·5	252·7	32·0	151·2	66·5	73·0
	From 18-VIII-24 to 8-IX-24	154·5	277·3	31·5	147·4	66·5	71·7
	From 15-IX-24 to 6-X-24	135·3	258·4	29·2	127·9	50·1	75·4
	From 12-X-24 to 3-XI-24	139·5	173·8	32·3	87·1	44·1	73·8
	From 10-XI-24 to 17-XI-24	89·9	119·6	15·3	43·1	21·9	36·4
		796·7	1280·1	165·6	762·0	324·5	405·0
6	From 23-VI-24 to 14-VII-24	141·0	195·0	25·3	136·3	71·8	74·7
	From 21-VII-24 to 11-VIII-24	161·8	222·9	32·0	104·6	53·3	73·0
	From 18-VIII-24 to 8-IX-24	156·7	259·4	31·5	95·1	50·0	71·7
	From 15-IX-24 to 6-X-24	144·0	230·6	29·7	58·7	33·6	75·4
	From 12-X-24 to 3-XI-24	134·4	253·8	32·3	24·7	32·5	73·8
	From 10-XI-24 to 17-XI-24	72·2	108·6	15·3	12·3	15·6	36·4
		810·1	1270·3	166·1	431·7	256·8	405·0
7	From 23-VI-24 to 14-VII-24	160·1	214·3	25·3	186·3	74·7	74·7
	From 21-VII-24 to 11-VIII-24	184·6	250·2	32·0	202·9	63·0	73·0
	From 18-VIII-24 to 8-IX-24	168·3	271·7	31·5	220·0	56·1	71·7
	From 15-IX-24 to 6-X-24	164·6	266·2	29·7	194·1	63·6	75·4
	From 12-X-24 to 3-XI-24	183·6	259·8	32·3	136·4	63·1	73·8
	From 10-XI-24 to 17-XI-24	89·7	123·3	15·3	67·8	31·3	36·4
		950·9	1385·5	166·1	1008·4	352·7	405·0
8	From 23-VI-24 to 14-VII-24	146·0	223·1	25·3	199·6	75·4	74·7
	From 21-VII-24 to 11-VIII-24	161·4	245·7	32·0	129·2	75·0	73·0
	From 18-VIII-24 to 8-IX-24	161·0	260·0	31·5	116·6	74·9	71·7
	From 15-IX-24 to 6-X-24	160·1	259·6	29·6	125·2	55·9	75·4
	From 12-X-24 to 3-XI-24	169·2	235·9	32·3	124·1	40·7	73·8
	From 10-XI-24 to 17-XI-24	78·1	113·6	15·3	61·6	20·3	36·4
		875·8	1337·9	166·0	756·3	342·2	405·0

Table II.

Average composition of food-stuffs for the entire feeding period in terms of dry substance.

	Hay	Silage	Lucerne	Groundnut cake	Brewery grain	Grain mixture
Crude protein	2·31	5·70	21·7[illegible]	57·31	18·00	16·00
Ash	7·63	8·28	11·03	1·7[illegible]	[illegible]·16	7·50
Ether extract	1·50	1·87	2·80	8·07	1·85	4·53
Crude fibre	41·06	39·85	29·90	1·86	13·25	23·36
Nitrogen free extract . .	17·50	41·21	31·52	25·01	60·14	58·01

Table III.

Average live weights (in pounds).

Week ending	Cow 1	Cow 2	Cow 3	Cow 4	Cow 5	Cow 6	Cow 7	Cow 8
	Av. live weight	Av. live weight	Av. live weight	Av. live weight	Av. live weight	Av. live weight	Av. live weight	Av. live weight
23-VI-24 . . .	896·3	927·3	862·2	680·6	771·6	777·0	901·[illegible]	813·5
30-VI-24 . . .	890·7	938·0	876·1	682·7	737·3	771·6	898·0	810·0
7-VII-24 . . .	890·6	913·7	880·3	680·1	771·1	801·7	890·0	826·1
14-VII-24 . .	887·1	914·3	881·0	686·1	782·0	788·7	871·6	825·1
28 days . . .	891·2	938·1	871·0	684·6	765·5	784·5	891·9	818·0
21-VII-24 . .	881·1	917·0	885·0	700·1	771·8	788·7	890·0	831·0
28-VII-24 . .	893·7	941·0	907·7	701·6	785·1	800·0	901·6	816·1
4-VIII-24 . . .	901·3	930·1	870·1	695·7	792·1	801·3	893·3	827·3
11-VIII-24 . .	903·6	936·9	891·1	698·9	784·7	805·7	900·0	826·1
28 days . . .	895·67	938·9	888·5	695·7	781·2	798·9	896·4	832·7
18-VIII-24 . .	D. Expt.	D. Expt.	D. Expt.	D. Expt.	D. Expt.	D. Expt.	D. Expt.	D. Expt.
25-VIII-24 . .	,,	,,	,,	,,	,,	,,	,,	,,
1-IX-24 . . .	917·1	942·7	892·4	708·4	798·0	831·8	909·7	848·4
8-IX-24 . . .	917·6	950·7	897·0	711·8	797·1	836·1	919·1	866·8
28 days . . .	917·3	946·7	891·7	710·1	797·7	833·9	914·9	851·6
15-IX-24 . . .	914·7	961·3	888·9	716·1	801·4	835·9	918·4	860·7
22-IX-24 . . .	908·8	970·5	891·1	716·4	808·0	831·1	916·5	816·7
29-IX-24 . . .	911·7	972·7	903·0	716·6	818·1	843·8	926·0	863·5
6-X-24 . . .	921·5	974·0	916·4	725·4	813·7	851·4	920·1	866·4
28 days . . .	914·2	969·6	899·8	718·5	808·5	841·3	921·0	859·3

Table III—*concld.*

Average live weights (in pounds)—concld.

Week ending	Cow 1	Cow 2	Cow 3	Cow 4	Cow 5	Cow 6	Cow 7	Cow 8
	Av. live weight	Av. live weight	Av. live weight	Av. live weight	Av. live weight	Av. live weight	Av. live weight	Av. live weight
12-X-24 . . .	918·5	966·3	913·6	722·5	819·0	851·0	924·8	875·6
17-X-24 . . .	921·5	971·5	900·8	712·8	823 3	..	921·8	874·8
22-X-24 . . .	928·1	980·0	909·7	722 0	..	839 6	940·0	..
27-X-24 . . .	D. Expt.	..	..	..	832·1	856·7	..	877·8
3-XI-24 . . .	932·0	976·2	921·0	719·7	825·0	851·5	939·0	878·5
	925·0	973·5	911·3	719·2	824·9	849·7	931·5	876·6
10-XI-24 . . .	924·5	979·2	917·2	921·0	827·2	862·0	938·4	878·2
17-XI-24 . . .	932·1	958·2	918·1	713·1	825·4	862·0	932·5	873·7
14 days . . .	928·3	968·7	917·6	717·0	826·3	862·0	935·4	875·9
Average weight for the entire period.	912	955·0	897	708	801	828	915	853
Gain in live weight .	37·1	30·3	42·7	32·1	60·8	77·5	43·5	57·0

Table IV.

Maintenance requirements.

Cow No.	Average live weight lb.	Per day			For entire feeding period		
		Net energy Therms	Nutrients lb.	Protein lb.	Net energy Therms	Nutrients lb.	Protein lb.
1	912	5·643	7·453	·688	868·9	1147·7	98·31
2	956	5·823	7·691	·669	896·7	1184·7	103·05
3	897	5·581	7·371	·628	859·4	1135·1	96·70
4	708	4·766	6·295	·496	734·2	969·5	76·32
5	801	5·175	6·835	·561	796·9	1052·8	86·35
6	828	5·291	6·988	·580	814·7	1076·1	89·26
7	915	5·654	7·467	·641	870·7	1150·0	98·64
8	853	5·397	7·128	·597	831·1	1097·7	91·95

Table V.

Milk yields

Week ending	Cow No. 1		Fat per cent.	Total fat	Week ending	Cow No. 2		Fat per cent.	Total fat
	Milk yield	Daily average				Milk yield	Daily average		
23-VI-24	282·00	40·28	4 80		23-VI-24	186·50	26·61	3 8	
30-VI-24	290·75	41·53	4 89		30-VI-24	188·50	26·92	3·81	
7-VII-24	289·25	41·32	4·55		7-VII-24	190·00	27·14	3·84	
14-VII-24	270·25	38·60	4·58		14-VII-24	185·00	26·40	3·82	
	1132·25	40·43	4·73	53·533		750·00	26·775	3·817	28·631
21-VII-24	276·25	36·46	4·51		21-VII-24	185·50	26·40	3·968	
28-VII-24	289·75	41·39	4·12		28-VII-24	180·25	27·75	3·775	
4-VIII-24	301·00	43·00	4·43		4-VIII-24	172·25	24·60	3·820	
11-VIII-24	282·25	40·35	4·07		11-VIII-24	174·50	24·92	3·924	
	1149·25	41·05	4·282	49·413		712 50	25·317	3·872	25·139
18-VIII-24	270·75	38·39	4·20		18-VIII-24	169·75	24·25	3·93	
25-VIII-24	269·00	38·40	4·14		25-VIII-24	165·50	23·60	3·81	
1-IX-24	256·75	36·68	4·50		1-IX-24	157·25	22·40	3·83	
8-IX-24	244·50	34·90	4·49		8-IX-24	145·25	20·70	3·92	
	1041·00	37·09	4·332	45·175		637·75	22·737	3·872	24·814
15-IX-24	222·75	31·82	4·15		15-IX-24	143·00	20·42	3·94	
22-IX-24	219·75	31·39	4·00		22-IX-24	141·50	20·21	3·62	
29-IX-24	224·75	32·10	4·75		29-IX-24	133·25	19·30	3·94	
6-X-24	218·20	31·20	4·66		6-X-24	124·75	17·75	3·97	
	885·45	31·63	4·390	38·958		542·50	19·42	3·867	20·984
12-X-24	189·25	31·52	4·726		12-X-24	102·75	17·12	4·111	
17-X-24	160·00	32·00	4·560		17-X-24	82·225	16·45	4·070	
22-X-24	153·00	30·60	4·660		22-X-24	78·75	15·75	4·080	
27-X-24	150·25	30·05	4·420		27-X-24	74·25	14·85	4·180	
3-XI-24	208·25	29·75	4·740		3-XI-24	103·00	14·70	4·180	
	860·75	30·78	4·621	39·927		440·975	15·770	4·124	18·195
10-XI-24	201·25	28·46	4·68		10-XI-24	95·00	13·57	4·12	
17-XI-24	191·25	27·32	4·89		17-XI-24	96·25	12·32	4·68	
	392·50	27·89	4·785	18·827		191·25	12·945	4·4	7·961
Total for entire period.	5461·2	..	..	245·833		3264·5	..	..	125·724
Average fat per cent. for entire period.	4·49	..	..	..		3·95	..	..	..

TABLE V—*contd.*

Week ending	Cow No. 3 Milk yield	Cow No. 3 Daily average	Fat per cent.	Total fat	Week ending	Cow No. 4 Milk yield	Cow No. 4 Daily average	Fat per cent.	Total fat
23-VI-24 . .	155·25	22·17	3·75		25-VI-24 . .	170·25	24·32	4·53	
30-VI-24 . .	160·25	22·89	3·88		30-VI-24 . .	177·25	25·32	4·53	
7-VII-24 . .	159·50	22·78	3·68		7-VII-24 . .	183·50	26·21	4·64	
14-VII-24 . .	151·25	21·60	3·61		14-VII-24 . .	177·00	25·28	4·65	
	626·25	22·36	3·73	23·387		708·00	25·28	4·59	32·485
21-VII-24 . .	156·00	22·28	3·78		21-VII-24 . .	176·75	25·25	4·530	
28-VII-24 . .	155·75	22·25	3·85		28-VII-24 . .	175·50	25·07	4·695	
4-VIII-24 . .	144·25	20·60	4·20		4-VIII-24 . .	174·00	24·85	4·820	
11-VIII-24 . .	147·00	21·00	4·31		11-VIII-24 . .	175·25	25·60	4·810	
	603·00	21·53	4·03	24·286		701·50	25·19	4·713	33·059
18-VIII-24 . .	134·50	19·21	4·20		18-VIII-24 . .	169·75	24·25	5·07	
25-VIII-24 . .	127·50	18·10	4·36		25-VIII-24 . .	168·50	24·00	5·07	
1-IX-24 . .	131·00	18·70	4·10		1-IX-24 . .	159·25	22·70	5·30	
8-IX-24 . .	135·25	19·30	4·11		8-IX-24 . .	152·00	21·70	5·46	
	528·25	18·82	4·19	22·258		649·50	23·16	5·22	34·010
15-IX-24 . .	125·25	17·89	3·77		15-IX-24 . .	145·50	21·78	5·40	
22-IX-24 . .	120·25	17·17	4·29		22-IX-24 . .	143·75	20·53	5·34	
29-IX-24 . .	125·50	19·90	4·10		29-IX-24 . .	137·00	19·50	5·59	
6-X-24 . .	121·00	17·30	4·35		6-X-24 . .	131·75	18·80	5·70	
	492·00	17·56	4·13	20·330		558·00	20·17	5·51	30·08
12-X-24 . .	100·75	16·80	4·55		12-X-24 . .	113·50	18·90	6·00	
17-X-24 . .	75·00	15·00	4·60		17-X-24 . .	90·50	18·10	5·800	
22-X-24 . .	75·25	15·05	4·61		22-X-24 . .	80·00	17·20	6·590	
27-X-24 . .	72·75	14·55	4·00		27-X-24 . .	83·00	16·60	6·420	
3-XI-24 . .	204·25	14·89	4·408		3-XI-24 . .	117·75	16·82	6·450	
	528·00	15·258	4·444	19·085		484·75	17·524	6·243	31·06
10-XI-24 . .	109·25	15·60	4·47		10-XI-24 . .	114·25	16·32	6·48	
17-XI-24 . .	100·50	14·30	4·69		17-XI-24 . .	115·75	16·53	6·819	
	209·75	14·81	4·58	9·602		230·00	16·42	6·874	14·66
Total milk for entire period.	2887·3	..	..	118·964		3331·8	..	..	175·354
Average fat percent. for entire period.	4·11	..	..	..		5·28	..	..	..

TABLE V—*contd.*

Week ending	Cow No. 5		Fat per cent.	Total fat	Week ending	Cow No. 6		Fat per cent	Total fat
	Milk yield	Daily average				Milk yield	Daily average		
23-VI-24 . .	209·00	29·85	3·79		23-VI-24 . .	161 25	23·03	3·53	
30-VI-24 . .	206·50	29·50	3·81		30-VI-24 . .	156 0	22·28	3·63	
7-VII-24 . .	204·00	29·14	3·86		7-VII-24 . .	158 25	22·60	3·75	
14-VII-24 . .	186·25	26·60	4·30		14-VII-24 . .	149·0	21·22	3·85	
	805·75	28·77	3·94	31·670		624·50	22·28	3·69	22·804
21-VII-24 . .	182·50	26·07	4·00		21-VII-24 . .	138·0	18·22	3·66	
28-VII-24 . .	182·25	26·03	3·99		28-VII-24 . .	135·5	19·07	3·662	
4-VIII-24 . .	180·50	25·78	4·05		4-VIII-24 . .	128·75	18·39	3·58	
11-VIII-24 . .	176 25	25·18	4·09		11-VIII-24 . .	127·5	18·21	3·65	
	721·50	25·77	4 03	29 239		529 75	18·17	3·638	19·018
18-VIII-24 . .	177·75	25·39	4·10		18-VIII-24 . .	122·0	17·42	3·6	
25-VIII-24 . .	176 25	25·1	4 03		25-VIII-24 . .	120·25	17·18	3·68	
1-IX-24 . .	167·25	23·8	4 30		1-IX-24 . .	112·00	16·00	3·98	
8-IX-24 . .	158·50	22·6	4·25		8-IX-24 . .	106·00	15·14	4·16	
	679·75	24·22	4·30	28 288		460·25	16·44	3·85	18·293
15-IX-24 . .	153·25	21·89	4·24		15-IX-24 . .	95·5	13·64	4·12	
22-IX-24 . .	145·25	20 75	4·30		22-IX-24 . .	96·5	13·79	4·01	
29-IX-24 . .	138·25	19·75	4·50		29-IX-24 . .	89·25	12·75	4·20	
6-X-24 . .	135·00	19·29	4·40		6-X-24 . .	85·75	12·25	4·36	
	571·75	20·39	4·36	25·124		367·00	13·07	4·17	15·310
12-X-24 . .	111·50	18·58	4·48		12-X-24 . .	74·75	12 45	4·312	
17-X-24 . .	88·25	17·75	4·50		17-X-24 . .	61·25	12·25	4·080	
22-X-24 . .	88·25	17·65	4·40		22-X-24 . .	60·25	12·05	4·100	
27-X-24 . .	85·50	17·10	4·50		27-X-24 . .	57·25	11·45	4·060	
3-XI-24 . .	115·25	16·46	4·48		3-XI-24 . .	77·50	11·07	4·400	
	488·75	17·08	4·47	21·910		331 00	11 87	4·180	13·824
10-XI-24 . .	105·00	15·0	4·54		10-XI-24 . .	73 25	10·46	4·20	
17-XI-24 . .	88·25	12·6	5·21		17-XI-24 . .	68 25	9·75	4·51	
	193·25	13·8	4·87	9·380		141 5	10 105	4·40	6·229
Total milk for entire period.	3463·8	..	..	145·611		2452 0	..	..	95·738
Average fat per cent. for entire period.	4 25	..	..	..		3 89	..	..	..

TABLE V—*concld.*

Week ending	Cow No. 7 Milk yield	Cow No. 7 Daily average	Fat per cent.	Total fat	Week ending	Cow No. 8 Milk yield	Cow No. 8 Daily average	Fat per cent.	Total fat
23-VI-24 . .	202·25	28·89	4·1		23 VI-24 . .	211·50	30·21	3·2	
30-VI-24 . .	206·00	29·42	4·19		30-VI-24 . .	210·75	30·10	3·26	
7-VII-24 . .	205·50	29·35	4·2		7-VII-24 . .	210·25	30·03	3·35	
14-VII-24 . .	189·25	27·03	4·40		14-VII-24 . .	193·25	27·60	3·49	
	803·00	28·67	4·23	33 918		825·75	29·48	3·32	27·235
21-VII-24 . .	183·25	26·17	4·34		21-VII-24 . .	191·50	27·35	3·475	
28-VII-24 . .	192·75	27·53	4·77		28-VII-24 . .	184·75	26·39	3·42	
4-VIII-24 . .	199·00	28·42	4·19		4-VIII-24 . .	184·25	26·32	3·54	
11-VIII-24 . .	201·50	28·78	4·30		11-VIII-24 . .	188·25	26·89	3·65	
	776·50	27·72	4·10	33·229		748·75	26·73	3·515	26·403
18-VIII-24 . .	204·00	29·14	4·09		18-VIII-24 . .	188·75	26·96	3·60	
25-VIII-24 . .	204·00	29·14	4·01		25-VIII-24 . .	190·25	27·10	3·45	
1-IX-24 . .	195·50	27·90	4·30		1-IX-24 . .	183·50	26·1	3·78	
8-IX-24 . .	185·75	26·25	4·30		8-IX-24 . .	166 25	23·7	4 07	
	789·25	28·17	4·17	29·191		728·75	25 98	3·725	27·091
15-IX-24 . .	185·75	26·53	4·31		15-IX-24 . .	158·25	22 6	4·1	
22-IX-24 . .	180·25	25·75	4·28		22-IX-24 . .	159·25	22·75	3·8	
29-IX-24 . .	180·75	25·82	4·29		29-IX-24 . .	154·00	22·0	3·95	
6-X-24 . .	175·50	25·00	4·26		6-X-24 . .	147·50	21·07	3·99	
	722·25	25·79	4·28	30·985		619·00	22·105	3·90	24·395
12-X-24 . .	151·50	25·25	4·292		12-X-24 . .	126·25	21·04	4·001	
17-X-24 . .	123·25	24·65	4·321		17-X-24 . .	102·75	20·55	4·065	
22-X-24 . .	119·50	23·9	4·310		22-X-24 . .	99·75	19·95	3·96	
27-X-24 . .	177·25	23·45	4·300		27-X-24 . .	98·00	19·60	3·90	
3-XI-24 . .	160·25	22·89	4·200		3-XI-24 . .	136·25	19·46	4·2	
	731·75	24·028	4·304	25·050		563·00	20·12	4·025	22·880
10-XI-24 . .	152·25	21·75	4·280		10-XI-24 . .	131·5	18·46	4·200	
17-XI-24 . .	144·75	20·67	4·715		17-XI-24 . .	128·5	18·35	4·234	
	297·00	21·21	4·497	13·350		260·0	18·405	4·217	10·989
Total milk for entire period.	4050·8	..	..	105·732		3745·3	..	..	138·946
Average fat per cent. for entire period.	4·29	..	..	..		3·71	..	..	..

TABLE VI.

A. Digestion coefficients used for computations in Table IV of text.

	Protein	Fibre	Nitrogen free extract	Fat
Hay	..	54	47	37
Silage	38·6	58	63	53
Lucerne	74	42	72	38
Mixture	72	29	66	67
Cake	90	9	84	90
Brewery grains	81	40	57	89

B. Coefficients used for computations in Table VII Appendix.

	DIGESTED PER 100 LB. DRY SUBSTANCE			
	Protein lb.	Organic matter lb.	Total nutrients lb.	Net energy Therms
Hay	4·28	49·73	51·23	43·23
Silage	2·62	55·70	58·33	48·75
Lucerne	13·04	55·73	57·71	46·25
Mixture	11·00	54·32	59·38	51·19
Cake	47·93	78·84	88·91	104·80
Brewery grains	19·09	61·41	69·30	60·29

TABLE VII.

Calculation of nutrients and net energy used for milk production.

No.	Total milk yield lb.		Computed Nutrients			Actually Digested Nutrients		
			Crude protein lb.	Nutrients lb.	Net energy. Therms	Crude protein lb.	Nutrients lb.	Net energy. Therms
1	5461·2	Total digested . .	519·1	2967·0	2625·7	— 420·7	2803·0	2502·0
		Maintenance .	98·3	1147·7	869·0	98·3	1147·7	869·0
		Available for milk .	450·8	1820·2	1756·7	322·4	1655·3	1633·0
		Used per lb. milk .	·0826	·3333	·3217	·0590	·3034	·2990
2	3261·5	Total digested . .	406·9	2355·5	2090·0	295·8	2081·1	1870·0
		Maintenance . .	103·1	1184·7	896·7	103·1	1181·7	896·7
		Available for milk .	303·8	1170·8	1193·3	192·7	899·4	973·3
		Used per lb. milk .	·0931	·3587	·3655	·0590	·2755	·2981
3	2887·3	Total digested . .	368·5	2035·1	1805·9	279·6	1971·5	1775·0
		Maintenance . .	96·7	1135·1	859·4	96·7	1135·1	859·4
		Available for milk .	271·8	900·0	916·5	182·9	836·4	916·6
		Used per lb. milk .	·0911	·3117	·3278	·0634	·2897	·3175
4	3331·8	Total digested . .	405·3	2259·5	2002·2	300·1	2010·1	1797·0
		Maintenance . .	76·3	969·5	734·2	76·3	969·5	734·2
		Available for milk .	329·0	1290·0	1268·0	223·8	1040·6	1062·8
		Used per lb. milk .	·0988	·3872	·3806	·0672	·3123	·3190
5	3463·8	Total digested . .	405·5	2271·2	2011·8	291·1	1975·2	1768·0
		Maintenance . .	86·4	1052·0	796·9	86·4	1052·3	796·9
		Available for milk .	319·1	1218·9	1214·9	207·7	922·9	971·1
		Used per lb. milk .	·0921	·3510	·3508	·0600	·2664	·2804
6	2452·0	Total digested . .	337·6	2017·1	1774·2	240·1	1845·2	1646·0
		Maintenance . .	89·3	1076·1	814·7	89·3	1076·1	814·7
		Available for milk .	248·3	941·0	959·5	150·8	769·1	831·3
		Used per lb. milk .	·1013	·3838	·3913	·0615	·3137	·3392
7	4059·8	Total digested . .	456·0	2584·2	2286·3	354·2	2390·5	2137·0
		Maintenance . .	98·6	1150·0	870·7	98·6	1150·0	870·7
		Available for milk .	357·4	1431·2	1415·6	257·6	1240·5	1266·3
		Used per lb. milk .	·0880	·3533	·3487	·0635	·3056	·3119
8	3745·3	Total digested . .	418·8	2359·1	2090·8	314·8	2177·8	1051·0
		Maintenance . .	92·0	1097·7	1831·1	92·0	1097·7	831·1
		Available for milk .	326·8	1361·4	1259·7	222·8	1080·1	1119·9
		Used per lb. milk .	·0873	·3632	·3365	·0595	·2884	·2990

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Silage Experiments at Nagpur

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SILAGE EXPERIMENTS AT NAGPUR.

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The process of making silage is an ancient one. Numerous experiments have been made in the past in Europe, and during the present time a very important series of investigations is being carried out at Cambridge University. In the United States of America, silage is made much use of, mainly because in that country maize is more commonly grown than roots, and maize silage provides the stock with succulent food in winter.

It would seem that the process of silage-making ought to be largely encouraged in India. Indian agriculture depends largely on the bullock for draught purposes. The use of improved implements is often objected to on the ground that they overtax the bullocks. Hence better bullocks are required. For these a more plentiful supply of food will be necessary. The supply of milk in India is hopelessly inadequate and pure milk in India is more expensive than in England. The Agricultural Department has given much attention in various parts of India to the improvement of the milk yield of Indian cows. But as the milk yield of a cow is increased, it requires a corresponding increase of food, hence it will be useless to produce cows of high milk yield unless an increased quantity of food is also produced on which to feed them. The Agricultural Department has done much towards producing increased food supplies by introducing better varieties of fodder crops.

In many parts of India these fodder crops can only be produced in the rains. Difficulty is commonly experienced in providing the animals with a sufficient supply of succulent fodder during the hot weather, and for this reason the making of silage should prove of great advantage to Indian agriculture. The essential point about silage-making in India is that an excess of green fodder can be grown during the rains and this excess can be cut into small pieces and stored without drying until the next hot weather. The fodder must be packed tight to keep out air. In other countries

the fodder is stored in stacks, in pits in the ground, in brick towers, and in one case in England funnels taken from a steamer wrecked near the shore were used. In India, however, the method of storage must be cheap, and it has been found that the storing of the green fodder in a pit dug in the ground gives quite satisfactory results. Silage-making has been practised on many Government farms in India for some years past, and at Nagpur it has been found invaluable and is an established practice.

It has been stated that the process consists in storing green fodder in a moist state until the hot weather when green food is difficult or impossible to obtain. Since a certain amount of fermentation takes place during storage there is bound to be a loss of some of the material so stored.

The silage produced at Nagpur has not always been of the same quality. It has varied in colour from black to green and yellow. At times, it is much drier than at others and in a few instances the smell has been very unpleasant.

Experiments were, therefore, carried out at Nagpur during 1924-25 in order to determine the conditions required for making a good quality silage. In addition, determinations were also made of the loss in weight and of the change in the food value of the green fodder during the process of silage-making.

Method of experiment.

The fodder used was *juar* (*Sorghum vulgare*). It was cut up with a Ghel fodder cutter worked by a Fiat tractor. At intervals during the filling of each pit a heap of the cut fodder was collected. This was filled by handfuls into a weighed sack and every fifth handful was put aside. When the sack was full, an ordinary clinical thermometer was put inside in the middle of the fodder and the sack sewn up and weighed. The fodder put aside during the filling of the sack was packed tight in a glass jar and removed to the laboratory for immediate analysis. The sack was placed in the pit and its exact position (*e.g.*, height above bottom of pit and distance from sides of pit) recorded. The filling of the pit was then proceeded with. Except in the case of one pit, which was too small, two bags were buried in each pit, one near the bottom and the other towards the top of the pit. When the pits were opened and a bag uncovered, it was immediately weighed. The contents were taken out and carefully weighed and the temperature as recorded by the clinical thermometer was noted. A portion of the silage was also taken for immediate analysis in duplicate.

Description of experiments.

The experiments can be divided into three groups :—

1. *Telinkheri Dairy, Nagpur.*

Two pits were under experiment here. Both were at the top of a hill and were dug in the solid trap rock and were rectangular in form.

Pit No. 1. The fresh fodder was allowed to fall into the pit during chaffing, being sprinkled with a small amount of water during filling. The dimensions of the pit were : length 27′, depth 9′, breadth 13′. Two bags (Nos. 1 and 2) were placed centrally in the pit, one at 6′ 6″ from the bottom and the other 2′ 8″ from the bottom.

Pit No. 2. The crop was allowed to wither for 12 hours in the sun and was then chaffed into the pit. No water was sprinkled on the crop. The dimensions of this pit were : length 20′, breadth 12′, depth 9′. Two bags (Nos. 3 and 4) were placed in the pit at 4′ 9″ and 2′ 9″, respectively, from the bottom.

2. College Farm, Nagpur.

Here the pits were dug not in rock but in black cotton soil. Two pits were used and were circular in form.

Pit No. 3. The fresh fodder was allowed to fall into the pit during chaffing, being sprinkled with a small amount of water during filling. The pit was 6′ deep and had a diameter of 18′ at the top and 14′ at the bottom. Two bags (Nos. 5 and 6) were placed centrally in the pit at 3′ 7″ and 2′ 4″, respectively, from the bottom.

Pit No. 4. This was filled as in the case of Pit No. 3, but no water was sprinkled on the crop. It was a small pit, 5′ deep and 11′ in diameter at the top and 9′ at the bottom. Only one bag (No. 7) was placed in the pit at 2′ from the bottom.

3. College tower silo.

This is a cylindrical brickwork silo lined with cement. It is 11′ in diameter, extending 6′ below the ground and 18′ above and is roofed. The fodder was chaffed and blown directly into the silo and was sprinkled with water during filling. Two bags (Nos. 8 and 9) were placed in position, one 9′ above ground level and one at ground level, *i.e.*, 6 feet above the bottom of the silo.

Opening of the Silos.

The pit silos had all been covered with a layer of earth, and when this was removed, a thin layer of mouldy silage had to be discarded in each case. In the case of pit No. 2 in which the crop had been withered in the sun before chaffing, this loss was probably the highest.

In the case of the tower silo, however, the top mouldy layer was very dry, and immediately beneath it, for distance of some feet, the silage was deep black in colour. The temperature was abnormally high, a thermometer thrust 6″ below the surface recording 68°C. The leaf structure had disappeared from the silage and it appeared to be largely carbonised. When shaken with water, it went quickly into a fine pulp and the liquid smelt strongly of caramel. It was strongly acid

in character but was eaten by the animals though without much relish. An analysis was made of this substance and is referred to in the paper.

Beneath the black layer, was a layer, several feet in thickness, of a deep brown colour and below this a yellow layer in which our top bag was found (Bag No. 9). Analyses of these brown and yellow layers are given later. In all these layers the temperature was still very high and a reading of 62°C. was recorded beneath the top bag, the clinical thermometer in the bag being, of course, broken owing to the high temperature. The silage had shrunk some inches away from the walls all around and the outside layer was mouldy, dry and quite useless for feeding. The silage in the bottom part of the pit, *i.e.*, below ground level, was of a different type, being similar in character to the pit silages, and the temperature only reached just over 38°C. These conditions appear to be explained by the fact that the tower is exposed to the full sun and during the hot weather the sun temperature at Nagpur must frequently reach 60°C. It would appear necessary to protect tower silos in India from the direct sun by some kind of efficient shade.[1]

Table I summarizes the information obtained from the bags.

[1] Since these remarks were written our attention has been called to the fact that Amos and Woodman (*J. Agri. Sci.*, XV, 1925, p. 447) observed a temperature of 60·5° C. in a clamp silo at Cambridge.

TABLE I.

—	TELINKHERI				COLLEGE FARM				
	Pit No. 1		Pit No. 2		Pit No. 3		Pit No. 4	Tower silo	
No. of bag	1	2	3	4	5	6	7	8	9
Position of bag	Top	Bottom	Top	Bottom	Top	Bottom		Top	Bottom
Max. temp. °C.	41·7	39·6	44·1	37·0	41·4	36 6	38·8	62·0	39·4
Wt. of green fodder in lb. as ensiled	51·00	51·25	52·56	40·62	45·62	41·37	47·87	49·93	42·00
Wt. of silage produced lbs	52·00	53 40	51·50	40·25	47·10	43·00	46·37	48·00	45·31
Per cent. moisture as ensiled	74·30	74·50	68·20	67·60	68·60	70·60	65·20	68·60	63·60
Per cent. moisture in silage	77·90	77·00	70·20	72 20	74·40	73·72	68·46	69·80	69·13
Dry matter as ensiled. lb.	13 05	13·02	16·6	13·09	14·26	12·13	16 62	15 63	15 24
Dry matter in silage. lb	11 50	12·24	15·36	11·18	12·20	11·30	14·62	14·50	13·99
Per cent. loss of dry matter	11·90	6·00	8·80	14·60	14·40	7·50	12 00	7·20	8·20
Date of ensilage	10-10-24	9-10-24	27-10-24	26-10-24	10-10-24	10-10-24	17-10-24	16-10-24	15-10-24
Date of removal	7-5-25	11-5-25	5-6-25	6-6-25	12-5-25	14-5-25	28-5-25	17-6-25	6-7-25

The conditions under which the various silages were made have already been described. The losses in dry matter vary greatly, from 6 to 14 6 per cent. This is about the range of variation in loss of dry matter found by Amos and Woodman[1] at Cambridge.

As stated above, the Telinkheri pits were in trap rock and the College Farm pits in black soil, but Table I gives no indication of any difference in the product due to this. There is, however, a wide variation in the moisture content of the silages. Pits No. 1 and 3 had water sprinkled on them during filling and pits No. 2 and 4 had none ; the crop in pit No. 2 having in addition been withered in the sun for 12 hours. It is, therefore, not surprising that the silage in bags No. 4, 3, and 7 is much lower in water content than that in 1, 2, 5 and 6. In this connection, it will be noticed that in the watered pits Nos. 1 and 3 the weight of the silage obtained was greater than the amount of fodder put in, owing of course to the water added, whereas, in pits 2 and 4 receiving no water, the reverse was the case. It is perhaps surprising that the watering had no effect on the maximum temperature reached. It must, however, be kept in mind that, though the maximum temperature reached was approximately the same, yet there might have been very great difference in the rate of rise of temperature shortly after the pits were filled. If this were so, we might expect differences in the types of silages produced, but the chemical analyses gave no indication of this.

The conditions in the tower silo were so different from those obtaining in the pits that the results must be considered separately. The moisture content of the silage is on the low side in spite of the fodder having been watered. It will be noticed, however, that the green crop when ensiled was comparatively dry particularly in the case of the bottom bag where the moisture content of the crop was 63·6 per cent. only. This bottom bag has gained considerably in weight probably due to liquid squeezed down by the great depth of silage above it.

Note on quality of silage produced in the various bags.

Bag No. 1. Green, smell pleasant, slightly fruity with a slight pungency. Very like contents of bag No. 5. Eaten readily by cattle. Very hot, temperature still up to 41·7°C. on opening.

Bag No. 2. Green, smell much more pungent and acid than No. 1. Very hot, temperature on opening up to maximum recorded *viz.*, 39·6°C.

Bag No. 3. Dark green, pleasant acid smell but not pungent. Very hot, temperature still up to 41·4°C. on opening.

Bag No. 4. Dark red brown and only slightly green, smell much the same as bag No. 3. Temperature much lower but still up to 37°C., the maximum recorded on opening.

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[1] *Journ. Agri. Sci.*, XII, 1922, p. 342.

Bag No. 5. Very similar to bag No. 1, but temperature was much lower. Since the maximum temperature was the same as in bag No. 1, fermentation must have subsided considerably in bag No. 5.

Bag No. 6. No difference from bag No. 5.

Bag No. 7. Olive green, sample felt dry, pit quite cool, hence fermentation subsiding. A sweet pleasant fruity smell, neither acid nor pungent- quite different from all other samples. As will be seen in table II this silage was the least acid of all the samples being especially low in volatile acid content.

Bag No. 8. Leaves dark green, stems yellow and general appearance of silage dark yellow. Colour darkened rapidly on exposure to air. Smell acid and neither pungent nor unpleasant. Still very hot, up to 62°C., but since maximum temperature recorded was 68·7°C. fermentation appears to be subsiding.

Bag No. 9. Yellow green, smell of ac tic acid, slightly pungent. Temperature about equal to maximum recorded 39 4°, hence fermentation not yet subsiding.

It will thus be seen that in the Telinkheri pits (bags 1 to 4) fermentation had not begun to subside when the bags were taken out since at that time the temperature in these bags was up to the maximum recorded.

In the case of all the pits at Nagpur Farm, fermentation has subsided considerably at the time the bags were removed. It will be remembered that the Telinkheri pits are dug in rock and the Nagpur Farm pits in the black cotton soil, and it may be that the black cotton soil is cooler than the rock and so tends to cool down the fermenting mass more rapidly than does the rock.

In the case of the tower silo the fermentation in the top bag (No. 8) appeared to be subsiding, but it showed no sign of subsiding in the bottom bag although that was removed nearly 3 weeks later.

Method of analysis.

Moisture was estimated in duplicate portions of 200 grm. of both the green fodder and silage in the usual manner. The dried residue was finely ground and submitted to complete analysis.

Analyses were also made in all cases of the aqueous extract of the green crops and silage samples by the methods used by Amos and Woodman.[1] Those authors have set out the advantages of these methods and we have found them very convenient. They provide a very convenient way of estimating volatile and non-volatile acids and, in addition, give a measure of the amino-acids and volatile bases present.

[1] *Journ. Agri. Sci.*, XII, 1922, p 345.
Journ. Agri. Sci., XV, 1925, p. 343.

Table II.

Showing changes in content of dry matter, volatile organic acids, amino-acids and volatile bases undergone in the various silos per 1,000 grm. dry juar. The figures show the equivalent of the acids or bases in cc. N alkali or acid respectively.

Telinkheri.

—	Pit No. 1				Pit No. 2			
	Green *juar*	Bag 1 top	Green *juar*	Bag 2 bottom	Green *juar*	Bag 3 top	Green *juar*	Bag 4 bottom
Volatile organic acids	87·0	475·8	50·6	802·6	50·1	266·9	69·8	280·0
Non-volatile organic acids	87·7	750·6	108·6	686·6	106·8	480·0	243·9	710·6
Amino-acids	4·2	148·5	4·3	178·3	3·3	30·3	6·6	49·6
Volatile bases	12·7	109·1	12·8	91·7	11·7	57·7	13·1	90·8
Dry matter grm.	1000	852	1000	891·9	1000	901·1	1000	837·2
College Farm.								
	Pit No. 3				Pit No. 4			
Volatile organic acids	87·4	683·2	32·9	548·4	59·9	195·6		
Non-volatile organic acids	178·1	148·4	109·4	673·9	208·4	419·4	..	..
Amino-acids	5·2	65·2	3·6	24·0	4·6	14·8	..	..
Volatile bases	22·3	68·9	11·8	69·0	1·5	44·5	..	..
Dry matter	1000	815	1000	898·6	1000	868·4	..	..
College Farm Tower Silo								
Volatile organic acids	48·5	294·1	31·6	444·1	..	..	..	..
Non-volatile organic acids	160·7	608·2	105·3	508 8	..	..	..	..
Amino-acids	1·7	21·1	1·4	38·1	..	..	..	..
Volatile bases	7·6	47·1	9·4	19·0	..	..	..	..
Dry matter	1000	902·2	1000	891·1	..	..	..	..

TABLE III.

Constituents of silage extract expressed as percentages of moisture-free silage.

—	TELINKHERI				COLLEGE FARM							
	Pit No. 1		Pit No. 2		Pit No. 3		Pit No. 4	Tower silo				
No. of bag . . .	1 top	2 bottom	3 top	4 bottom	5 top	6 bottom	7	8 top	9 bottom	black top layer	brown top layer	Yellow layer below brown
Volatile organic acids* .	3·35	5·40	1·77	2·01	5·03	3·66	1·35	1·96	2·99	5·02	4·35	1·91
Non-volatile organic acids†	7·93 (5·96)	6·93 (4·66)	4·78 (2·55)	7·63 (4·19)	1·64 (—0·22)	6·75 (5·09)	4·35 (1·95)	6·02 (3·98)	5·14 (3·63)	8·59	8·02	4·92
Amino acids‡ . . .	1·52	1·75	0·35	0·52	0·70	0·24	0·15	0·20	0·37	0·00	0·00	0·15
Volatile bases‡ . .	1·12	0·90	0·56	0·95	0·74	0·67	0·45	0·46	0·19	0·31	0·44	0·25

* Calculated as acetic acid.
† Calculated as lactic acid.
‡ Calculated as crude protein.

The high content of non-volatile organic acid in the black and brown layers at the top of the tower silo is of interest in view of Woodman's remark[1] that when the temperature rises above 50°C. the fermentation is dominated by lactic acid bacteria.

Amos and Woodman (*loc. cit.*) found that in normal silages produced by them the non-volatile acids largely exceeded the volatile organic acids in amount. All our bags contained normal silage and, with the exception of No. 5, the non-volatile acids exceeded the volatile acids. However, Amos and Woodman have corrected the amount of non-volatile acids found in the silage by deducting the non-volatile acids found in the green fodder. They did this because they obtained evidence that this non-volatile acid portion was not lactic acid. They noticed during the titration of the extracts of the green crop and of the resulting silage with soda, the development of a yellow colour. We also observed this phenomenon to some extent. We have inserted in the brackets the figures obtained by deducting the non-volatile acid titration figure obtained for the corresponding green fodder. The preponderance of non-volatile organic acids over the volatile organic acids is then much less marked. Bag No. 5 considered by us our best sample then shows a minus quantity for non-volatile organic acids.

A comparison of our figures for the green fodder with those obtained by Amos and Woodman (*loc. cit.*, p. 348) shows that our green fodder contained much more volatile organic acid, distinctly less non-volatile organic acid, much less amino-acid and slightly less volatile bases. Our silages contained rather more volatile acids than the samples produced at Cambridge by Amos and Woodman. In general, the non-volatile organic acids were about the same in amount as found by them and our volatile bases rather less, but the amount of amino-acids in our samples were far lower than found by them. This is only to be expected since a reference to table IV shows that our green fodder contained only 2·5 to 5 per cent. of crude protein reckoned on dry matter, whereas the Cambridge green oats and tares contained from 11 to 13 per cent. A low ratio of amino-acids to volatile bases was considered by Amos and Woodman (*loc. cit.*, p. 356) as chemical evidence of spoiling. This seems a reasonable view, but we could not describe our samples as spoilt.

[1] *Journ. Min. of Agri.* 1925, XXXII, No. 2, p. 126.

TABLE IV.

Amounts of constituents of green juar and of silage produced therefrom. Calculated on dry matter.

TELINKHERI PIT NO. 1.

—	Bag 1 (top)		Bag 2 (bottom)	
	Green juar	Silage	Green juar	Silage
Crude protein	4·76	4·80	4·02	4·57
Ether extract (1)	1·22	2·10	1·27	2·66
N-free extractives	59·15	58·46	59·55	55·01
Crude fibre	27·42	25·28	26·55	27·33
Ash	7·43	9·36	8·71	10·43
True protein	3·40	3·67	2·95	3·00
"Amides"	1·36	1·13	1·07	1·57

—	Bag 1			Bag 2		
	Green juar	Silage	Per cent. increase or loss	Green juar	Silage	Per cent. increase or loss
	oz.	oz.		oz.	oz.	
Moist material	816	832	+ 2·0	820	854·4	+4·2
Dry matter (2)	208·8	184·0	—11·9	208·3	195·8	—6·0
Organicmatter (2)	193·3	166·7	—13·8	190·1	175·4	—7·7
Crude protein	9·9	8·5	—14·0	8·4	8·5	+1·4
Ether extract (2)	2·5	10·0	+293·1	2·6	15·8	+496·4
N-free extractives	123·5	104·1	—15·7	124·1	102·2	—17·6
Crude fibre	57·3	44·9	—21·6	55·3	50·8	—8·2
Ash	15·5	16·6	+7·2	18·1	19·4	+6·8
True protein	7·1	6·5	—8·0	6·1	5·6	—9·3
"Amides"	2·8	2·0	—29·2	2·2	2·9	+30·9

(1) Not taking into account the volatile organic acids of the silage.
(2) Allowance made for silage volatile organic acids as acetic acid.

TABLE IV—*contd.*

Amounts of constituents of green juar and of silage produced therefrom. Calculated on dry matter.

TELINKHERI PIT NO. 2.

—	BAG 3		BAG 4	
	Green juar	Silage	Green juar	Silage
Crude protein	3·52	3·38	5·07	5·00
Ether extract (1)	0·83	1·71	1·17	2·00
N-free extractives	59·45	61·45	57·00	58·65
Crude fibre	27·79	23·92	28·77	25·26
Ash	8·40	9·54	7·98	9·09
True protein	1·96	2·73	2·58	3·94
"Amides"	1·56	0·69	2·49	1·05

—	BAG 3			BAG 4		
	Green juar	Silage	Per cent. increase or loss	Green juar	Silage	Per cent. increase or loss
	oz.	oz.		oz.	oz.	
Moist material	841	824·0	—2·0	649·9	644·0	—0·9
Dry matter (2)	267 0	245 8	—8·8	209·4	178·9	—14·6
Organic matter (2)	244·6	222·4	—9·1	192·7	162·7	—15·6
Crude protein	9·4	8·2	—13·2	10·6	8·8	—17·4
Ether extract (2)	2·2	8·6	+285·9	2·5	7·2	+192·8
N-free extractives	158 8	148·4	—6·5	119·3	102·9	—13·7
Crude fibre	74·2	57·8	—22·2	60·3	44·3	—26·5
Ash	22·4	23·0	+2·6	16·7	15·9	—4·6
True protein	5·2	6·6	+25·9	5·4	6·9	+27·9
"Amides"	4·2	1·7	—60·0	5·2	1·8	—64·7

(1) Not taking into account the volatile organic acids of the silage

(2) Allowance made for silage volatile organic acids as acetic acid.

TABLE IV—*contd.*

Amounts of constituents of green juar and of silage produced therefrom. Calculated on dry matter.

—	COLLEGE FARM PIT NO. 3				COLLEGE FARM PIT NO. 4	
	BAG 5		BAG 6		BAG 7	
	Green juar	Silage	Green juar	Silage	Green juar	Silage
Crude protein	3·51	3·34	2·97	3·32	2·70	2·52
Ether extract (²)	1·63	2·04	1·48	2·68	1·18	1·46
N-free extractives . .	50·17	54·40	59·62	60·22	60·21	65·05
Crude fibre	29·55	20·04	27·32	23·68	28·50	21·32
Ash	9·13	11·18	8·59	10·10	7·89	9·65
True protein	2·52	2·72	2·52	2·65	2·32	2·29
" Amides "	1·00	0·62	0·46	0·67	0·39	0·23

—	BAG 5			BAG 6			BAG 7		
	Green juar	Silage	Per cent. increase or loss	Green juar	Silage	Per cent. increase or loss	Green juar	Silage	Per cent. increase or loss
	oz.	oz.		oz.	oz.		oz.	oz.	
Moist material	729·9	753·6	+3·2	661·9	688·0	+3·9	765·9	741·9	—3·1
Dry matter (²)	228·2	105·2	—14·4	191·1	180·8	—7·5	265·9	233·9	—12·0
Organic matter (²)	207·3	173·4	—16·3	177·4	102·6	—8·3	244·9	211·3	—13·7
Crude protein	8·0	6·2	—22·5	5·8	5·8	±0	7·2	5·8	—19·0
Ether extract (²)	3·7	1·38	+270·0	2·9	11·5	+209·3	3·1	6·6	+109·5
N-free extractives	128·1	101·2	—21·0	115·7	105·0	—9·2	160·1	150·2	—6·2
Crude fibre	67·4	54·0	—19·9	53·0	41·3	—22·1	75·8	49·2	—35·0
Ash	20·8	20·8	±0	16·7	17·6	+5·6	21·0	22·3	+6·2
True protein	5·8	5·1	—12·0	4·9	4·6	—5·5	6·2	5·3	—14·3
" Amides."	2·3	1·2	—49·5	0·9	1·2	+30·9	1·0	0·5	—48·8

(¹) Not taking into account the volatile organic acids of the silage.
(²) Allowance made for silage volatile organic acids of the acetic acid,

College Farm Tower Silo.

—	Bag 8		Bag 9		Not from bags		
	Green juar	Silage	Green juar	Silage	Black top layer	Brown layer below*	Yellow layer below *
Crude protein	2·60	2·92	2·55	2·94	2·97	2·78	2·59
Ether extract (1)	1·44	2·40	1·47	2·38	2·62	2·20	2·42
N-free extractives	58·38	57·94	59·63	55·85	69·22	68·56	62·45
Crude fibre	29·36	28·12	27·05	27·40	16·43	17·90	23·13
Ash	8·20	8·62	9·30	11·43	8·76	8·56	9·41
True protein	2·00	2·07	2·00	1·96	2·93	2·39	1·98
"Amides"	0·60	0·85	0·54	0·98	0·04	0 39	0·63

—	Bag 8			Bag 9		
	Green juar	Silage	Per cent increase or loss	Green juar	Silage	Per cent. increase or loss
	oz.	oz.		oz.	oz.	
Moist material	798·9	768·0	—3·9	672·0	725	+7·9
Dry matter (2)	250·1	232·0	—7·2	243·8	223·8	—8·2
Organic matter (2)	229·6	212·0	—7·7	221·2	198·2	—10·4
Crude protein	6·5	6·6	+2·2	6·2	6·4	+2·7
Ether extract (2)	3·6	10·1	+181·0	3·6	12·0	+235·1
N-free extractives	146·0	131·8	—9·7	145·4	121·3	—16·6
Crude fibre	73·4	64·0	—12·9	66·0	59·5	—9 7
Ash	20·5	19·6	—4·3	22·7	24·8	+9·3
True protein	5·0	4·7	—5·8	4·9	4·3	— 12·7
"Amides"	1·5	1·9	+28·9	1·3	2·1	+61·7

(1) Not taking into account the volatile organic acids of the silage.
(2) Allowance made for silage volatile organic acids as acetic acid.

Discussion of results.

1. *Change in total weight of crop during ensilage.*

(a) Moist weight

No. of pit	1		2		3		4	Tower Silo	
No of bag	1	2	3	4	5	6	7	8	9
Percentage change of total weight	+2	+1·2	−2·0	−0·9	+3·2	+3·9	−3·1	−3·9	+7·9

Pits Nos. 1 and 3 were sprinkled with water during filling, hence the gain in weight is to be expected. The green fodder in 2 was dried in the sun before chaffing and sampling and no water was sprinkled on it, nor on No. 4. In these two pits, all the bags lost weight. During the filling of the tower silo, water was sprinkled on the fodder. Bag No. 8 has lost weight probably for 2 reasons—firstly owing to the high temperature developed and secondly by drainage owing to the large weight of crop in the silo. Bag No. 9 has gained in weight since it was lower down in the silo than No. 8 and absorbed juice squeezed out from above.

(b) Dry matter.

No. of pit	1		2		3		4	Tower Silo	
No. of bag	1	2	3	4	5	6	7	8	9
Percentage change of weight of dry matter.	−11·9	−6·0	−8·8	−14·6	−14·4	−7·5	−12·0	−7·2	−8·2

None of these losses can be considered excessive. Such variations as exist between the various samples do not appear to be connected in any way with the kind of pit, addition of water, percentage of moisture in crop or temperature reached during ensilage. Bag No 5, in which one of the largest losses occurred, produced the best silage.

Special remarks on tower silo. It will be remembered that abnormal temperatures were developed in the upper part of this silo. Various types of silages were in consequence produced at different levels. We have given analysis of bags 8 and 9 which represent the type of silage about half way up the silo and 3 to 4 feet from the bottom respectively. We have also analysed 3 samples of silage near the top.

No. 1. The black layer 2 feet from the top.

No. 2. A dark brown black layer. This was about 2 feet thick.

No. 3. A yellow layer. This was perhaps 4 feet thick and the sample taken for analysis was just above the top bag.

It will be convenient to summarize the analyses of these five samples together.

Composition of dry matter of silage from different levels in the Tower silo.

	Black top layer	Brown black layer	Yellow layer.	Top bag	Bottom bag
Volatile organic acids	5·02	4·35	1·91	1·96	2·99
Non-volatile organic acids	8·59	8·02	4·92	6·02	5·14
Amino acids	0·00	0·00	0·15	0·20	0·37
Volatile bases	0·31	0·44	0·25	0·46	0·19
Crude protein	3·04	2·84	2·59	2·92	2·94
Ether extract	2·62	2·20	2·42	2·40	2·38
N-free extractives	69·15	68·50	62·45	57·94	55·85
Crude fibre	16·43	17·90	23·13	28·12	27·40
Ash	8·76	8·56	9·41	8·62	11·43
True protein	2·46	2·38	1·96	2·07	1·96
"Amides"	0·58	0·46	0·63	0·85	0·98
Maximum temperature°C	69	68	..	62	39·40

These results are of interest in that the top black and brown layers were somewhat low in amides. The crude fibre in the black and brown layers was abnormally low and in consequence the Nitrogen-free extractives show a great increase.

2. *Changes in the nitrogenous constituents.*

It has already been stated that the crude protein content of our green crop as ensiled was only 2·5 to 5 per cent. reckoned on the dry matter, whereas the green oats and tares ensiled at Cambridge contained 10-13 per cent. This difference must be taken into account in considering the changes in the nitrogenous constituents. Amos and Woodman found that during ensilage the proportion of true to crude protein diminishes. Our figures are as follows

Amount of true protein expressed as percentage of crude protein.

Bag No.	1	2	3	4	5	6	7	8	9
Green juar	71·7	72·5	55·3	51·0	72·5	84·5	86·1	76·9	79·0
Silage	76·5	72·6	80·5	78·4	82·3	79·3	91·2	71·2	77·2

Before considering these figures it will be of advantage to combine the results obtained in the analysis of the dry matter of the samples with those obtained in the titration of the extracts, as suggested by Amos and Woodman, in order to show in what form the "Amide" fraction existed.

[1] *Journ. Agri. Sci.*, XII, 1922, p. 354.
[2] *Journ. Agri. Sci.*, XII, 1922, p. 356.

Per 100 grm dry matter, nitrogen expressed throughout as protein.

No. of bag	TELANKHERI								COLLEGE FARM						TOWER SILO			
	1 TOP		2 BOTTOM		3 TOP		4 BOTTOM		5 TOP		6 BOTTOM		7		8 TOP		9 BOTTOM	
Percentage	Green crop	Silage	Green crop	Silage	Green crop	Silage	Green crop	Silage	Green crop	Silage	Green crop	Silage	Green crop	Silage	Green crop	Silage	Green crop	Silage
Amino-acid, etc . .	0·04	1·52	0·04	1·75	0·03	0·35	0·06	0·52	0·05	0·70	0·03	0·24	0·04	0·15	0·02	0·20	0·01	0·37
Volatile bases . . .	0·11	1·12	0·11	0·90	0·10	0·56	0·11	0·95	0·20	0·74	0·10	0·67	0·01	0·45	0·07	0·46	0·08	0·19
True amides . .	1·21	1·51	0·92	1·08	1·43	0·22	2·32	0·42	0·75	0·82	0·33	0·24	0·24	0·37	0·51	0·19	0·45	0·42

A study of the above two sets of figures shows results of interest when compared with the figures obtained by Amos and Woodman (*loc cit.*). With regard to the first set of figures those authors found that the proportion of true protein to crude protein was much less in silage than in the green crop from which it was produced. One would naturally expect this to be so, but our figures do not lend themselves to similar conclusions. In only 3 cases, *viz.*, bags 6, 8 and 9, are our results in agreement with those of Amos and Woodman, and even in these cases the difference is not so great as found by them. Except in the case of bags 3 and 4, probably none of the differences fall much outside the experimental error. Bags 3 and 4 are of special interest since it will be remembered that the green crop was exposed for 12 hours to the sun before being filled into the silo and sampled. During this drying, the protein seems to have undergone a large amount of hydrolysis since the ratio of true protein to crude protein was only 55·3 and 51·0 per cent. respectively, the corresponding ratio in all other samples being well over 70 per cent. The proportion of true to crude protein in the silage from bags 3 and 4 was, however, high, *viz.*, 80·5 and 78·4 per cent. respectively. It certainly seems as though in these bags there has been a gain in true protein at the expense of the " Amide " portion.

Our figures are peculiar in that the amount of amino-acid added to the volatile bases exceeds the " amide " figure obtained by analysis of the dry matter in the silage of all bags except Nos. 8 and 9. This is shown by the minus figures for amides in the second set of figures above. This is probably explained by the loss of ammonia from the silage during the preparation of dry matter.

Our results are in agreement with those of Amos and Woodman in that they show that the amino-acids form only a small proportion of the " amides " in the green crop and a much larger proportion in silage.

Amos and Woodman [1] consider the disappearance of true protein with the production of the corresponding amount of amide to be typical of good silage. The absence of this change they consider to be chemical evidence of spoiling. Our silage gave no signs of being spoilt. hence in this respect our results are not in agreement with theirs.

Amos and Woodman[2] found a high ratio of amino-acid to volatile bases in unspoilt silage. On this point also our results are at variance with theirs.

In comparing our results with those of Amos and Woodman we must again emphasise the very low nitrogen content of our green fodders as compared with theirs. This difference makes a comparison difficult.

3. *Change in ether extract.*

The increase in ether extract during ensilage after allowing for volatile acids was much greater in our experiments than in those of Amos and Woodman. The increase is largely due to the increased amount of organic acids and calls for no special

[1] *Loc.* cit., 1922, p. 355.
[2] *Loc.* cit., 1922, p. 357.

remarks except that we agree with Amos and Woodman that lactic acid cannot be the only non-volatile organic acid present in quantity.

The following table illustrates this point.

Bag No.	PERCENTAGE ON DRY MATTER OF SILAGE.								
	1	2	3	4	5	6	7	8	9
Non-volatile acidity calculated as lactic acid.*	5·96	4·66	2·55	4·10	—0·22	5·00	1·95	3·98	3·63
Ether extract	2·10	2·66	1·71	2·00	2·04	2·68	1·46	2·40	2·38

* After deducting non-volatile acidity of green fodder

4. *Change in crude fibre.*

The amount of crude fibre decreased during the process of ensilage in all cases. The figures are summarized below :—

Percentage loss of crude fibre during ensilage.

Bag No.	1	2	3	4	5	6	7	8	9
	21·6	8·2	22·2	26·5	19·9	22·1	35·0	12·9	9·7

The loss is especially great in pit 2 (bags 3 and 4) and in pit 4 (bag No. 7) which, it will be recalled, were not sprinkled with water during filling. A consideration of bag No. 7 (table IV) indicates fairly clearly that the crude fibre breaks down to form N-free extractives.

Bag No 7.

Percentage in dry matter	Green fodder	Silage
Nitrogen-free extractives	60·21	65·05
Crude fibre	28·50	21·30

Probably owing to the conversion of the N-free extractives into organic acids this change of crude fibre to Nitrogen-free extractives is not so marked in all cases, but it is distinct in the cases of bags 3 and 4 also.

5. *Changes in the Nitrogen-free extractives.*

Owing partly to the low nitrogen content of our green fodder, the Nitrogen-free extractives are 10 per cent. greater in the dry matter of our green fodder than in that grown at Cambridge by Amos and Woodman. It is probably owing to this

fact that our silages are distinctly more acid than theirs. We have considered the relation of fibre to Nitrogen-free extractives in the previous section.

6. *Changes in the inorganic constituents.*

These do not call for much remark. Usually it is found that the silage at the bottom of a pit contains the highest ash content owing to washing down of the soluble ash constituents from above. This is well illustrated by the tower silo in which the top and bottom bags contained 8·62 and 11·43 per cent. of ash in drv matter restipecvely.

Our thanks are due to Mr Ram Narayan Kayasth, M.Sc., B.Ag., Assistant to the Agricultural Chemist, for help rendered in connection with the analytical work.

SUMMARY.

Experiments have been carried out at Nagpur in order to determine the amount of loss and the change in composition taking place during the conversion of green *juar* fodder (*Sorghum vulgare*) into silage. The experiments were carried out in three types of silos.

1. Pits dug in the trap rock.
2. Pits dug in the black cotton soil.
3. A tower silo built of brick and lined with cement.

The effect of varying the moisture content by either withering the crop in the sun or by the addition of water was also examined.

The following conclusions may be drawn :—

1. *Juar* fodder contains only from one-fourth to one-half as much nitrogenous materials as does the green fodder, *e.g.*, oats and tares[1] and maize[2] used in English experiments. The nitrogen-free extractives are in consequence much higher in the Indian material.

2. Good samples of silage were produced which were readily eaten by cattle. There seems to be no advantage derived from sprinkling the crop with water or from withering in the sun previous to ensilage.

3. No differences in the composition of the silage or in the losses occurring could be observed between silage produced in pits dug in the black cotton soil and in trap rock respectively. There is some indication that the fermentation ceases more quickly in the black soil pits than in the rock pits. As regards the tower silo, that portion of the silage which was below ground level showed no obvious differences from silage produced in pits. In the above ground portions of the silo, however, the temperature had run up abnormally high. This is almost certainly due to the

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[1] Amos. and Woodman. *Loc. cit.*
[2] Annet and Russell. *Journ. Agri. Sci.*, 1908, II, p. 382.

exposure of the outside of the silo to the direct sun.[1] The temperature in the top layer of this reached 69°C and just above ground level was 62°C. In consequence, the top few feet of the silage were black and caramelization had taken place. This black substance was, however, strongly acid and was eaten by cattle though not with great relish.

In all other cases the maximum temperatures reached were on the high side, varying from 36·6 to 44·1°C. None of our silages were sour silages and in this respect our work confirms that of Amos and Williams[2].

4. The total change in weight after ensilage was very small in all cases, usually amounting to 2 or 3 per cent. either way except in the case of the bottom bag (No. 9) in the tower silo. This gained 7·9 per cent. in weight and this gain must have been due to drainage of juice from the great weight of silage above it. There was, however, a loss of dry matter varying from 6 to 14·4 per cent. This appeared to be least in the tower silo, but, otherwise, the differences observed do not seem to be in any way related to the various conditions under which the silage was made.

The losses in weight above referred to do not take into account losses at the top of the silos through mould development. These losses were greatest in the tower silo, because in addition to a loss at the top there was much shrinkage from the walls due to the great heat developed and this outside layer was thoroughly mouldy and useless. In the case of the pits, only the top layer was unfit for feeding.

5. Amos and Woodman (*loc. cit.*) found during the process of ensilage that the proportion ot pure to crude protein considerably diminished and considered this an indication of good silage. We have not observed this change. Indeed, in one case in which the green crop was wilted in the sun for 12 hours before ensiling, the proportion of pure to crude protein diminished to a great extent, yet in the resulting silage the proportion of pure to crude protein actually increased largely. This would actually indicate a resynthesis of protein from the " amide " fraction during ensilage. This is admittedly quite contrary to one's expectation.

Amos and Woodman also conclude that in good silage the ratio ot amino-acids to volatile bases is high. We found a low ratio in all cases. Possibly the difference between our results and those of Amos and Woodman is due to the low nitrogen content of our fodder.

6. Our silages contained much more volatile organic acid and distinctly less non-volatile acid than the Cambridge samples. Butyric acid appeared to be absent from all our samples.

7. Our results indicate that part of the crude fibre breaks down during ensilage into N-free extractive. Part of this, however, is changed to organic acid ; hence the gain in nitrogen free extractives due to the breaking down of the fibre is not always obvious.

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[1] Since these remarks were written our attention has been called to the fact that Amos and Woodman (*J. Agri. Sci.*, XV 1925, p. 447) observed a temperature of 60·5°C. in a clamp silo at Cambridge.

[2] Amos and Williams. *Journ. Agri. Sci.*, 1922, XII, p. 323.

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Nutrients required for Growth Production with Indian Food-Stuffs.

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NUTRIENTS REQUIRED FOR GROWTH PRODUCTION WITH INDIAN FOOD-STUFFS

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Object of the enquiry.

The present enquiry forms a companion to the nutrition work[1] on cows which was recently reported. In the first paper the requirements for milk production were studied. In the present paper the requirements for growth are dealt with. The object of the work was to determine the requirements for growth using Indian food-stuffs and to compare the results obtained with the standard rations which have been worked out for growing cattle in other countries.

Experimental procedure.

1. Two groups of six cross-bred heifers, the one group somewhat older than the other, were selected for the work. The details regarding their ages and live weights are given in Table VI. The food consumption of all the animals was accurately measured during a period of 116 days and the live weight increases during this time were determined by weighments on 3 consecutive days at regular intervals.

2. *Rations.* The rations given were those commonly used in the dairy here. The younger lot received daily 2 lb. of mixture (consisting of 7 parts bran, 3 parts cotton seed meal and 5 parts gram husk), 1 lb. of groundnut cake, 5 lb. silage and hay as much as they could eat The older lot received 3 lb. mixture, 1 lb. cake, 10 lb. silage and as much hay as they could eat.

3. *Feeding time-table.* Half the concentrate r tion, soaked overnight, was fed in the morning. Silage was fed after the concentrate had been licked up. The silage was usually finished up in less than half an hour. Any silage residue that there happened to be was removed and weighed. Hay was then fed in weighed amounts and the hay residues were removed after 1½ hours for weighment. The

[1] *Memo. Dept. Agri. India, Chem. Ser.* Vol. VIII, No. 9.

animals were then let loose in a bare paddock until 3 P.M. when they were tied up again. The afternoon feeding then proceeded exactly as above. The animals were let loose again at night usually at 9 P.M.

4. One of the animals (No. 8) became ill very soon after the experiment started. The symptoms were slight scouring and complete loss of appetite. It was treated and recovered condition, but for the major part of the experiment it was unwell. The remainder were quite well. All had a bright appearance throughout and put on weight satisfactorily, but they did not fatten appreciably on the ration given.

5. A digestion experiment with all the animals was undertaken on 16th September 1924 and concluded on 25th September 1924.

6. The experimental results will be considered under the following heads: (*a*) Digestion experiments, (*b*) Live weight increases, (*c*) Total food consumption and requirements for growth, (*d*) Comparison of our results with the Armsby [1] and Wolff Lehmann [2] feeding standards for growing dairy cattle.

Digestion experiments.

The results of the digestion experiment are shown in Table I. It will be noticed

TABLE I.

Actual digestion coefficients of the mixed ration.

No.	Dry matter	Organic matter	Crude protein	Ether extract	Crude Fibre	Nitrogen free extract	Carbo-hydrates	Nutritive ratio
1	47·94	50·88	60 90	73·10	56·77	42·58	48·53	5 971
2	51·57	54·15	62·52	74·64	58·11	47·70	52·13	6 577
3	49·00	52·02	62·69	74·81	58·88	46·37	49·52	5·642
4	49·29	52·64	62·15	67·46	57·04	45·33	50·21	5·515
5	48·90	52·13	58 60	74·45	57·05	44·95	50·11	6·887
6	52·24	55·12	62·23	76·15	57·64	48·03	52·58	5·915
AVERAGE	49·82	52·82	61·51	73·48	56·75	45·98	50·51	6·085
7	53·44	56·99	58·15	76·57	62·70	50 73	55·79	7·708
8	55·76	58·80	62 02	75·63	64·29	52·38	57·30	6·378
9	51·94	54·42	60 20	74·22	60·56	47·00	52·78	7·108
10	52·54	55·54	62 06	73·42	60·16	48·18	53·78	6·519
11	55·70	58·51	62 42	70·53	63·14	52·82	57·14	6·711
12	48·88	52·90	60·19	72·28	55·31	45·42	40·55	6·184
AVERAGE	53·04	56·21	60·84	73·77	61·03	49·42	54·39	6·825

that there are appreciable differences in the digestive capacities of individuals. The digestion of organic matter is found to vary between 50·9 per cent. and 55·1 per cent. for the younger group and between 52·9 per cent. and 58·9 per cent. for the older group. As the organic matter consists mainly of fibre and nitrogen free extract or taking the fibre and nitrogen free extract together, of carbohydrates, the digestion of fibre, nitrogen free extract, carbohydrates and organic matter run parallel with one another and any one of these sets of figures is equally representative of the individual variations in digestive capacity. The individual variations in protein and ether extract digestion are also appreciable, but the figures do not run parallel

[1] Armsby. *The Nutrition of Farm Animals.*
[2] Quoted by Henry and Morrison in *Feeds and Feeding.*

with the other results. Thus, while high digestion of carbohydrate is necessarily associated with high digestion of organic matter, it does not follow that the digestion of protein is also high. Another noteworthy point is that protein and ether extract are about equally well digested by the two groups. The most important fact brought out by this table is that the older group possesses a decidedly higher average digestive capacity for the ration as a whole. Of the total organic matter consumed the average amounts digested by the two groups were 56·2 per cent. and 52·8 per cent. respectively. This difference is due to the better digestion of fibre, nitrogen free extract and total carbohydrates by the older group. In spite of appreciable individual variations the group average digestion coefficients are distinctive for the two groups and may be applied to the individuals without serious error. The group averages will be employed later for important calculations. There are certain complications in these digestion results which must be considered next. In the first place, no two animals received rations of identical digestibility. This was due to the fact that concentrates and silage were fed in fixed amounts, whilst hay was given *ad lib.* and was consumed in very different amounts by the individuals. Therefore the proportion of the least digestible ingredient, the hay, was different for each animal. Secondly, the bulk of ration consumed in relation to the bulk or body weight of the animals varied considerably for different individuals. It is a well known fact that digestibility is materially influenced by the bulk consumed. The nutritive ratio of the food also varied and this doubtless influenced its digestibility also. Table II shows the extent to which these factors varied during the digestion experiment. We have now to consider whether these variations in the ration are responsible for observed variations in digestibility.

TABLE II.

Bulk and nature of ration consumed.

No	Total dry matter	CONSUMPTION IN LB.			Ratio Hay conc.	Ratio Rough conc.	Nutritive ratio	% digestion of dry matter
		PER 1000 LB LIVE WEIGHT						
		Hay	Hay and silage	Total dry wt.				
1	8·461	13·80	18·21	26 87	1·594	2·103	5·971	47·94
2	9·661	16·81	21·01	29·28	2·083	2·542	5·577	51·57
3	8·487	15·30	19·93	29·37	1·621	2·111	5·642	49·00
4	8·097	13·83	18·64	28·12	1·460	1·969	5·515	40·20
5	9·830	17·65	21·85	30·25	2·102	2·604	6·887	48·90
6	8·362	15·51	20·57	30·52	1 557	2·066	5·019	52·24
AVERAGE	8·817	15·48	20·03	29·07	1·728	2·232	5·918	49·82
7	12·361	11·65	17·08	24·20	1·636	2·390	7·708	53·44
8	9·954	9·57	15·54	23 99	1·134	1·842	6·378	55·76
9	13 341	13 84	19·37	26·64	1·906	2·668	7·503	51·94
10	11·170	11 82	17·04	25·28	1·436	2·070	6·519	52·54
11	11·060	11·88	17·96	26·77	1·349	2·030	6·711	55·70
12	11·201	10·22	16 15	23·92	1·315	2·077	6·134	48·88
AVERAGE	11·514	11·49	17·19	25·13	1·462	2·182	6·825	53·04

Taking first the nutritive ratio, digestion should be better with a narrow nutritive ratio. We find that No. 4 with the narrowest nutritive ratio has only average digestive capacity, whilst No. 2 with a wide nutritive ratio has attained a digestion which is above the average. In the older group No. 7 with a wide nutritive ratio has done better than No. 12 with a narrow ratio. In these cases the digestion is not proportional to the nutritive ratio. An examination of the ratio of hay to concentrate and of the bulks consumed per 1,000 lb. live weight show similarly that the differences found in the digestive capacity are not related to these factors. These examples show that in our experiment the factors considered do not vary sufficiently in degree to produce differences comparable with differences due to individual digestive capacity. The group averages, however, bring out one point which cannot be overlooked. The younger group consumed a larger bulk per 1,000 lb. (column 4) and more hay in proportion to concentrate (column 5). For these reasons digestion by the younger group should be lower, and it is so. It is an important matter from a practical feeders' point of view to know the rate at which young growing cattle develop a capacity for digesting roughage. From the average results of Table 1 it might be concluded that a marked increase in digestive capacity occurs during growth from 270 lb. live weight to 410 lb. live weight. We see now, however, that the observed difference in digestive capacity may be partly accounted for by differences in the bulk consumed and in the proportion of hay eaten. Our results, therefore, do not give any conclusive evidence regarding the rate of increase of digestive capacity. The figures of these two tables show, however, that for purposes of subsequent calculations the group average digestion results are significant and characteristic.

In Table III the actual digestion found by experiment is compared with the digestion obtained by computation using American coefficients but allowing for the fact that the protein of our hay and silage is somewhat less digestible than the American coefficients indicate. The coefficients used for the computation were as follows :—

—	Protein	Ether extract	Fibre	Nitrogen free extract
Hay	0	37	54	47
Silage	38·6	53	58	63
Mixture	72	67	29	66
Cake	90	89	49	57

In using these coefficients the actual average chemical composition of each of the foods consumed during the digestion experiment was taken into account. Table

III shows that the actual digestion of protein and nitrogen free extract is less than the computed amount, whilst the actual digestion of fibre and ether extract is more. In these respects the results agree with the similar c mparison of the computed and actual digestion effected by cows. Looking at the average results for the two groups it may be noted that the actual digestion of organic matter and carbohydrates is almost equal to the computed amount with the older group. With the younger group the actual digestion is decidedly lower than the computed. By both groups the fibre is actually better digested than computation indicates, but here

TABLE III.

Actual and computed digestion.

—	Organic matter	Protein	Fibre	Nitrogen free extract	Carbo-hydrates	Fat	Nutritive ratio
No. 1. Actual	50·88	60·90	56·77	12·58	48 53	73·10	5·971
Computed	56·41	69·51	50 53	56·16	53 08	67·89	5·420
Difference	—5 56	—8·61	+6·24	—13·88	—5·15	+7·21	
No. 2. Actual	51·15	62 52	58·11	47·70	52·13	74·64	6·577
Computed	55·48	67 46	51·06	55·24	53·16	66·11	6·172
Difference	—1·33	—4·94	+7·05	—7·51	—1·33	+8·23	
No. 3. Actual	52·02	62·09	53·88	16·37	19·52	71·81	5·642
Computed	56·35	69 49	50·52	56·33	53·90	67·85	5·439
Difference	—4·33	—6·80	+8·26	—0·96	—4·38	+6·96	
No. 4. Actual	52·62	62·15	57·04	15·33	50·21	67·46	5·515
Computed	56·79	70·16	50·33	56·91	51·17	68·38	5·189
Difference	—1 17	—8·01	+6·71	—11·58	—3·96	—0·92	
No. 5. Actual	52·13	58·60	57·05	11 95	50·11	74·15	6·887
Computed	55·35	67·20	51·12	55·07	53·38	66·21	6·282
Difference	—3·22	—8 60	+5·93	—10·12	—3·27	+8·21	
No. 6. Actual	55·12	62·23	57·61	18·93	52·58	76·15	5·919
Computed	56·51	69·69	50·18	56·58	51 01	68·03	5·356
Difference	—1·30	— 7·16	+7·16	— 7·65	— 1·13	+8·12	
Average difference	—3·33	—7·21	+5·98	—10·12	—3·30	+5·81	
No. 7. Actual	56·99	58·15	62·70	50 73	55 79	76·57	7·708
Computed	55·87	65 29	51·03	56·67	54·28	65·09	6·602
Difference	+1·12	—7·14	+11·67	—5·94	+1·51	+11·48	
No. 8. Actual	58·89	62·02	64·29	52·38	57·30	75·63	6·878
Computed	57·16	68·35	50·23	58·36	55 00	67·18	5·492
Difference	+1·73	—6·33	+14·06	—5·98	+2·30	+8·45	
No. 9. Actual	54·42	60 20	60·56	17·00	52·78	74·22	7·503
Computed	55·34	64·06	51 30	55·94	53·96	64·26	7·109
Difference	—0·92	—3·86	+9·26	—8·94	—1·18	+9·66	
No. 10. Actual	55·54	62·06	60·16	18·18	53·78	73·42	6·519
Computed	56·21	66·97	50·45	57·06	51·29	66·30	6·035
Difference	—0·67	—1·91	+9·71	—8·88	—0·51	+7·33	
No. 11. Actual	58·51	62·42	63·14	52·82	57·14	70·53	6·711
Computed	56·17	67·07	50·18	57·47	54·55	66·23	5·958
Difference	+2·04	—1·65	+12·66	—1·65	+2·59	+4·30	
No. 12. Actual	52·90	60 19	55·31	15·42	49·55	72·28	6·134
Computed	56·61	66·82	50·64	57·72	54·76	66·14	5·097
Difference	—3·71	—6 63	+4·67	— 12·30	—5·21	+6·14	
Average difference	—0·07	—5·59	+10·33	—7·78	—0·08	+ ·94	

again the older group shows a greater excess of actual over computed digestion. These figures prove in another way, *i.e.*, by comparison with a Standard, that the older group was more efficient than the younger group in carbohydrate digestion.

Finally, the table shows that the American coefficients used for the computation are not accurately applicable to our food-stuffs. There is, for instance, no reason why every animal should digest more fibre and less nitrogen free extract than the computed amounts. Further, from this table it would appear that the older group actually digested organic matter to an extent which was practically equal to the Standard. Seeing that the animals were consuming a fairly heavy productive ration of about 28 lb. per 1,000 lb. live weight, such efficient digestion does not seem likely. This affords another reason for concluding that the coefficients used for the computation are not strictly applicable to our food-stuffs.

Digestion experiments with bullocks on our food-stuffs were also carried out at Bangalore. With these digestion data the computed digestion by our heifers can be calculated exactly as it was done by using American coefficients. We thus obtain two sets of computed results, namely, those based on Bangalore bullock digestion experiments and those based on American coefficients. These two sets of computed values together with the actuals are shown in Table IV. In this table

TABLE IV.

Comparison of actual and computed digestion.

—	Actual digestion grm.	CRUDE FIBRE		Actual digestion grm.	NITROGEN FREE EXTRACT	
		EXCESS BY COMPUTATION			EXCESS BY COMPUTATION	
		American coefficients	Bangalore coefficients		American coefficients	Bangalore coefficients
No. 1	707·4	—77·7	+ 15·3	735·6	+ 239·8	+ 215·9
No. 2	854·0	—103·6	+ 0·6	945·8	+ 149·6	+ 131·5
No. 3	674·0	— 42·0	+ 50·9	803·5	+ 172·7	+ 147·5
No. 4	671·8	—79·1	+ 8·7	747·5	+ 101·0	+ 165·4
No. 5	856·5	—89·0	+ 23·4	908·0	+ 204·4	+ 187·6
No. 6	707·4	—87·9	+ 3·6	834·7	+ 130·4	+ 106·0
AVERAGE	745·2	—79·9	+ 18·1	820·2	+ 181·3	+ 159·0
No. 7	1178·9	—218·4	—81·7	1296·0	+ 152·0	+ 90·9
No. 8	925·7	—202·5	—90·7	1070·0	+ 122·0	+ 90·7
No. 9	1244·7	—190·3	—29·7	1299·4	+ 217·0	+ 190·7
No. 10	1019·5	—184·1	— 51·6	1110·2	+ 204·5	+ 155·0
No. 11	1080·4	—206·5	— 80·7	1203·8	+ 105·4	+ 48·0
No. 12	914·8	—77·1	+ 43·8	1047·2	+ 283·5	+ 216·8
AVERAGE	1051·5	—170·8	— 48·4	1171·1	+ 185·7	+ 127·0

the comparison has been limited to the figures for the digestion of fibre and nitrogen free extract and only the differences between the computed and actual amounts are shown. It should be noted too that the figures refer to the quantities of material digested and not to percentage digestion. The results are perfectly regular for each group and indicate that the Bangalore coefficients diverge less from the actuals

and are a better basis for estimating the digestibility of our foods by growing heifers. From the figures of Table IV the average computed and actual daily digestion effected by the two groups has been calculated and is shown in Table V. This table is an

TABLE V.

Group average computed and actual digestion in gm. per day.

		Fibre	Nitrogen free extract	Carbo-hydrates	Difference between computed and actual
Younger group	Actual	745·2	829·2	1574·4	..
	American Computation	665·3	1010·5	1675·8	101·4
	Bangalore Computation	763·3	988·2	1751·5	177·1
Older group	Actual	1051·5	1171·1	2222·6	..
	American Computation	871·7	1356·8	2228·5	5·9
	Bangalore Computation	1003·1	1298·1	2301·2	78·6

important summary of the digestion results obtained with the two groups and requires notice. The main point to be observed in Table V is that while the computation based on Bangalore digestion coefficients is nearer to the actual result both for fibre and for nitrogen free extract yet when we come to examine the carbohydrate figure (which is fibre+nitrogen free extract) we find that the Bangalore computation diverges more than the American computation from the actual. The reason for this peculiarity is made evident by an examination of the detailed data, but the significance of the difference remains to be considered. The Bangalore coefficients were determined by using the same food as that given to the heifers. There is no doubt that they must be a better measure of the digestibility of these foods than American coefficients determined from American foods. The meaning of the greater divergence of our Bangalore computation is made clear by examining the carbohydrate digestion effected by the older group of heifers. We find the actual digestion is practically equal to the computed amount obtained from American coefficients. But these heifers were on a heavy productive ration which is never quite so perfectly digested as a moderate ration. If the coefficients used are correct there ought to be a divergence and there is not. The divergence between the actual and Bangalore computation is in the right direction, and as far as we can judge, it represents the true differences in digestion which are due to the combined effects of age and ration bulk upon digestibility. We have to conclude that carbohydrate digestion was about 10 per cent. below normal in the younger group and 3·4 per cent. below normal in the older group

Live weight increases.

The data relating to live weights are shown in Table VI. The total live weights increase and the average daily increase are the most significant figures. They

TABLE VI.

Live weight increase.

—	1	2	3	4	5	6	7	8	9	10	11	12
Age in days at commencement of Expt.	290	254	253	249	247	239	459	453	440	434	429	421
Live weight on 22nd October 1924. in lb.	329·6	356·6	315·6	309·4	346·1	293·1	533·6	447·6	529·0	459·9	432·0	487·8
Live weight on 8th July 1924. in lb.	233·0	239·8	203·4	211·4	229·2	196·2	403·4	395·4	396·2	376·6	332·2	339·9
Increase in live weight	96·6	116·8	112·2	98·0	116·9	96·9	130·2	52·2	132·8	83·3	99·8	98·0
Increase per day	·919	1·112	1·068	·933	1·113	·923	1·239	·496	1·264	·792	·950	·934
Increase per 100 lb. initial weight.	48·45	48·71	55·16	46·37	51·02	49·41	32·25	..	33·52	22·20	30·04	25·14
Increase during consecutive 3 weeks.	37·2	30·3	30·6	33·4	40·1	26·7	55·6	1·8	44·4	31·5	31·1	39·3
	15·8	22·9	19·0	16·2	19·4	13·5	26·5	0·4	30·1	21·4	19·2	15·3
	19·3	26·6	22·3	15·0	27·9	25·3	24·5	20·1	22·9	11·1	16·3	15·1
	15·9	17·4	21·9	20·2	13·3	19·4	2·2	13·1	12·6	2·4	5·5	14·2
	8·3	19·5	18·3	13·2	15·7	11·7	21·3	27·1	22·8	16·8	16·2	14·0
Total	96·5	116·7	112·1	95·0	116·9	96·9	130·1	..	132·8	83·2	95·8	97·3
Increase 1st week	16·5	12·4	13·6	13·5	14·7	12·5	21·2	..	19·1	12·5	11·1	15·3
Increase for 14 weeks	90·0	104·3	98·5	94·2	102·2	94·4	108·[illegible]	..	113·7	70·7	87·7	32·6
Increase per day 14 weeks.	·916	1·074	1·005	·959	1·043	·961	1·114	..	1·160	·722	·895	·843
Average live weight during digestion expt.	31	3305	289	258	325	274	511	415	501	442	413	45[illegible]
Average live weight entire period.	281	298	260	260	255	245	464	..	463	418	382	437
Maintenance per day Protein lb.	·317	·330	·305	·307	·32[illegible]	·292	·442	..	·435	·407	·355	·42[illegible]
Maintenance per day Net energy therms.	2·550	2·630	2·350	2·400	2·[illegible]	2·3[illegible]	3·600	..	3·550	3·3[illegible]0	3·13	3·4[illegible]

measure the productive effect of the ration. The growth of all the younger group was satisfactory and fairly uniform, with Nos. 2 and 5 somewhat better than the others. Of the older group two did very well, two were moderate, one No. 10 was unsatisfactory and No. 8 was a failure. The last animal was ill for a part of the time as already mentioned and left large residues of its ration. As its food consumption could not be accurately determined it has been excluded from all further consideration. The figures giving increases during successive 3 week periods and during the first week show that the rate of increase was high at the commencement of the experiment. It is almost certain that a part of the increase at the initial stage was due to a sudden increase of food consumption with a consequent distention of the digestive tract. A similar effect has already been referred to in the case of cows, and other examples of the kind have been noted recently at Bangalore. Any serious effect due to distention may be discounted almost completely by excluding the first set of average weights. We thus obtain the average daily increase during 14 weeks. These figures will be used later for estimating the productive value of the ration. The 4th period calls for some remarks. This period included the digestion experiment and also a spell of very bad rainy weather. It will be noticed that most of the older group did badly during this time. We have to ask ourselves therefore whether this unfavourable result is to be attributed to restiveness under the constraints imposed by the experiment. There is no doubt that the animals were restive. No. 7 was particularly troublesome and No. 10 was not good. A great deal of time was spent in training these animals for the test. The failure to put on weight at this stage seems therefore to be clearly related to the inconvenience which the animals were subjected to. This conclusion is supported in a sense by the figures for the younger group. The latter were all docile and tame; they took to the new conditions without resistance and immediately, and they were quite unperturbed throughout the test. It will be noticed that these animals showed normal live weight increase during this period. From these facts it seems reasonable to conclude that the failure of the older group at this stage has to be attributed to their restiveness under the experimental conditions. On the other hand, it has to be noted that there was no falling off in food consumption at this time. Consumption was practically at its highest point and the digestion attained was very good. The assimilated nutrients and net energy being normal, it is scarcely to be credited that metabolism was so much increased by the conditions of the experiment as to stop growth. It is a well known fact that increase of body substance may be proceeding steadily, while the live weight undergoes great fluctuations due to differences in the amount of fluid retained in the alimentary tract. Differences of this kind in the fluid content can persist for considerable periods and it is possible that the anomalies in our live weight increases are due partly to such a cause. It may be remarked here also that if the metabolism had been very materially enhanced, the balance of food energy for productive purposes would have been correspondingly reduced and the apparent net energy required to produce a unit of body increase would have

become higher than the normal. Figures given later show that the gains were made fairly economically and therefore metabolism could not have been increased abnormally. It is clear from this lengthy discussion, however, that the older group suffered certain derangements during a part of the feeding test and the results obtained from them cannot be as uniform or as accurate as the results from the younger group.

Food consumption.

The total food consumed during the entire feeding test of 116 days is given in Table VII. This table requires very little explanation. The mixture, cake and

TABLE VII.

Total food consumption during 116 days in lb. dry matter.

No.	Mixture	Cake	Silage	Hay	TOTAL	Daily average	Group average dry matter
1 . .	212·6	103·3	134·3	473·1	923·3	7·958	
2 . .	218·9	..	134·3	597·1	1054·0	9·085	
3 . .	212·6	..	131·8	450·7	907·5	7·823	8·102
4 . .	206·4	..	134·3	448·5	892·6	7·695	
5 . .	218·9	..	133·2	577·7	1033·0	8·906	
6 . .	206·4	..	134·3	426·3	870·0	7·503	
7 . .	322·1	..	268·4	751·6	1445·0	12·460	
8 . .	322·1	..	268·2	753·8	1447·0	12·480	
10 . .	315·8	..	261·7	635·2	1316·0	11·340	11·082
11 . .	309·5	..	260·0	619·7	1293·0	11·150	
12 . .	315·6	..	261·2	593·9	1274·0	10·980	

silage were fed in fixed amounts and were practically completely consumed. Therefore the consumption of these ingredients was almost identical for all the animals in each group. The chief difference lies in the consumption of hay which was fed *ad lib.* and consumed according to each animal's capacity. The dry matter of each ingredient was determined daily throughout the experiment and composite samples were prepared for analysis. The average composition of the food-stuffs used is given in Table VIII.

TABLE VIII.

Average composition of food-stuffs in terms of dry substance.

—	Mixture	Cake	Silage	Hay
Crude protein	16·00	57·31	5·79	2·31
Ash	7·50	4·75	8·28	7·63
Ether extract	4·53	8·07	1·87	1·50
Crude fibre	23·36	4·86	39·85	41·06
Nitrogen free extract	58·61	25·01	44·71	47·50

Requirements for growth production.

The procedure employed for determining the requirements for growth production is exactly the same as that used and described fully in the paper on Requirements for milk production. The outline of the procedure is as follows. From the data for total food consumption the total digested nutrients and net energy are calculated. From this total is deducted the amount required for maintenance. The difference figure thus obtained is the amount of nutrient available for growth. The increase in weight being known we can calculate the amount of nutrient or net energy required per lb. of gain.

The total digested nutrients and net energy.

The determination of total digested nutrients and net energy has been made in three ways :—

1. By using standard American digestion coefficients exactly as in the case of the cows. The results of these calculations will be spoken of as the computed values. The factors used for this computation are given in Table IX.

TABLE IX.

Factors used for computed digestion. (These data are taken from Henry & Morrison and Armsby.)

—	Assimilated from 100 lb. dry substance			
	Protein	Organic matter	Total digestible nutrients	Net energy
Mixture	11·00	54·32	59·38	51·19
Cake	47·93	78·84	88·91	104·80
Silage	2·63	55·70	58·33	48·25
Hay	4·28	49·73	51·23	43·23

2. By using the digestion coefficients found for each animal by experiment. The results of these calculations will be spoken of as the individual values.
3. By using average digestion coefficients which were found to apply to each group. When discussing the digestion results (Table 1) it was pointed out that while there were appreciable individual differences in digestive capacity, on the whole there was a close agreement between all the animals belonging to one group, while there was a marked difference between the two groups. To bring these facts once more clearly to

our minds the average digestion attained by the two groups is given again here.

Digestion coefficients for the 2 groups of heifers.

—	Protein %	Ether extract %	Fibre %	Nitrogen free extract %	Total carbo-hydrates %	Total organic matter %
Younger group . .	61·51	73·43	56·75	45·98	50·51	52·82
Older group . . .	60·84	73·77	61·03	49·42	54·39	56·21

The total digested nutrients and net energy calculated from individual coefficients and group average coefficients are given in Table X.

TABLE X.

Comparison of total digestion determined by individual coefficients and group average coefficients.

—	Protein lb.	Total digestible nutrients lb.	Net energy therms	—	Protein lb.	Total digestible nutrients lb.	Net energy therms
No. 1.				*No. 7.*			
Individual . .	68·17	461·1	417·4	Individual . .	83·52	800·8	710·7
Average . . .	68·85	478·0	433·3	Average . . .	87·38	789·0	701·0
Difference . .	−0·68	−16·9	−15·9	Difference . .	−3·86	+11·8	+9·7
No. 2.				*No. 8.*			
Individual . .	72·39	557·2	501·6	Individual.			
Average . .	71·22	543·7	489·3				
Difference . .	+1·17	+13·5	+12·3				
No. 3.				*No. 9.*			
Individual . .	69·88	463·9	420·2	Individual . .	86·49	766·6	679·6
Average . . .	68·57	470·2	426·7	Average . . .	87·41	790·0	701·9
Difference . .	+1·31	−6·3	−6·5	Difference . .	−0·92	−23·4	−22·3
No. 4.				*No. 10.*			
Individual . .	68·60	459·0	418·5	Individual . .	86·60	727·0	649·2
Average . . .	67·89	462·5	420·0	Average . . .	84·89	719·6	642·1
Difference . .	+0·71	−8·5	−1·5	Difference . .	+1·71	+7·1	+7·1
No. 5.				*No. 11.*			
Individual . .	67·55	527·2	475·3	Individual . .	86·22	733·4	657·6
Average . .	70·91	533·4	480·5	Average . . .	84·04	707·6	631·7
Difference . .	−3·36	−6·2	−5·2	Difference . .	+2·18	+25·8	+25·9
No. 6.				*No. 12.*			
Individual . .	68·37	470·7	428·3	Individual . .	83·39	657·7	586·5
Average . .	67·58	451·3	410·5	Average . . .	84·29	697·5	623·2
Difference . .	+0·79	+19·4	+17·8	Difference . .	−0·90	−39·8	−36·7

The figures in this table give the total amounts of crude protein, total digested nutrients and net energy digested by each animal during the entire period of 116 days. We have to compare the results obtained with the individual and group average coefficients respectively. In both groups there are one or two animals which show appreciable divergences in the two sets of data. The greatest divergence (heifer No. 12) amounts to 6 per cent. of the total digested nutrients or net energy.

With No. 6 the divergence is 4·5 per cent., with 9 and 10 it is 3 per cent., and with the remainder it is about 1 per cent. The data show that the group average digestion coefficients give results which do not depart materially from the individual results. The use of these group average coefficients for calculating digested nutrients has this advantage that it represents the actual average digestion capacity found by experiment for animals of the type in question. By using individual coefficients our calculations are based on a single short period digestion experiment which might or might not be an accurate representation of the average digestion attained throughout the long period feeding test. As only one digestion experiment was done with each animal there is no check on the figures except the group average. We have in fact two sets of data available and taking everything into consideration, we have selected the group average data as less likely to be seriously wrong in any single case. In the future discussion the calculations from the group averages will be taken as the actual digestion. The figures derived from individual coefficients will not be used.

Comparison of computed and actual digested nutrients and net energy.

In Table XI the actual digested nutrients and net energy (calculated from group

TABLE XI.

Comparison of computed digestion with digestion determined from group average coefficients.

—	Protein	Total digestible nutrients	Net energy	—	Protein	Total digestible nutrients	Net energy
No. 1.				*No. 7.*			
Computed	96·67	538·9	486·3	Computed	124·15	824·7	727·4
Average	68·85	478·0	433·3	Average	87·38	789·0	701·0
Difference	27·82	60·9	53·0	Difference	36·77	35·7	26·4
No. 2.				*No. 8.*			
Computed	102·67	606·1	543·1				
Average	71·22	543·7	489·3				
Difference	31·45	62·4	53·8				
No. 3.				*No. 9.*			
Computed	96·03	530·7	479·4	Computed	124·31	825·6	728·3
Average	68 57	470·0	426·7	Average	87·41	790·0	701·9
Difference	27·46	60·7	52·7	Difference	36·90	35·6	26·4
No. 4.				*No. 10.*			
Computed	94·94	522 6	472·6	Computed	118·29	757·2	670·7
Average	67·89	462·5	420·0	Average	84·89	719·6	642·1
Difference	27·05	60·1	52·6	Difference	33·40	37·6	28·6
No. 5.				*No. 11.*			
Computed	100·80	595·5	534·2	Computed	116·92	745·3	660·4
Average	70·91	533·4	480·5	Average	84·04	707·6	631·7
Difference	29·89	62·1	53·7	Difference	32·88	37·7	28·7
No. 6.				*No. 12.*			
Computed	93·98	511·2	463·0	Computed	116·51	735·9	652·6
Average	67·58	451·3	410·5	Average	84·29	697·5	623·2
Difference	26·40	59·9	52·5	Difference	32·22	38·4	29·4

Older group average 95·3 per cent. computed net energy is assimilated.
Younger group average 89·8 per cent. computed net energy is assimilated.

average coefficients) are compared with figures obtained by computation using the American standard coefficients. The comparison made in Table XI is of considerable importance. It shows us the extent to which young growing animals are able to utilize food when the ordinary available digestion coefficients are used as a standard of digestibility. The average of these figures tells us that the older group assimilated 95 per cent. of the computed net energy and nutrients and the small deficiency is almost exactly equal to the deficiency in protein digestion. The younger group assimilated 89·3 per cent. of the computed net energy. The average computed and actual assimilation per head for each group has been calculated from these figures and is given in Table XII. The figures of Table XII are not required at present. They will be referred to later.

TABLE XII.

Daily group average computed and actual digestion of nutrients.

—		Crude protein in lb.		Total digestible nutrients in lb.		Net energy in therms	
		Computed	Actual	Computed	Actual	Computed	Actual
Younger group	Total	97·68	69·17	550·8	489·8	496·4	443·4
Per head	Daily	·842	·596	4·718	4·223	4·279	3·823
Older group	Total	120·01	85·6	777·7	710·7	687·9	680·0
Per head	Daily	1·035	·738	6·701	6·385	5·930	5·860

Maintenance requirements.

The maintenance requirement may be expressed either in terms of net energy or as total digestible nutrients which suffice to provide the energy. The average net energy required for the maintenance of an 1,000 lb. Ox is stated by Armsby to be 6 therms. The Haecker and Savage standards as tabulated by Henry and Morrison allow 7·925 lb. total digestible nutrients for maintenance. If these two standards are equal, 6 therms must be provided by 7·925 lb. total digestible nutrients or 1 therm=1·321 lb. total digestible nutrients. Table VI above gives both the computed net energy and nutrients assimilated by our animals from the rations fed. These computed values are derived from American coefficients of food-stuffs which have been thoroughly tested. The ratio of nutrients required to produce one therm of net energy is therefore to be relied on as accurate. The ratio varies somewhat according to the proportion of hay in the ration, but the range is not great, typical figures being 1·108, 1·117, 1·129, 1·136 or an average of 1·122 lb. total digestible nutrients per therm of net energy. Accordingly with our ration 6 therms =6·732lb. total digestible nutrients. If the same ratio were applied to the Haecker Savage maintenance standard of 7·925 lb. total digestible nutrients it would yield 7·063 therms net energy per 1,000 lb. live weight. The two standards differ to such

an extent that both cannot be employed. We will use the Armsby standard of 6 therms per 1,000 lb. live weight, and evidence will be produced later to show that it is probably a fair estimate. From this standard the maintenance requirements of our heifers have been calculated on the generally accepted basis that the maintenance requirement is proportional to the ⅔ power of the live weight. The average live weights for the entire period were used for this purpose. Both the live weights and the daily maintenance requirements according to this standard are given in Table VI.

Net energy available for growth.

By subtracting the maintenance requirement for the entire period from the total net energy assimilated (Table XI) the total excess available for productive purpose is obtained and from this figure the daily available excess has been calculated. The results of this calculation are shown in Table XIIIa. The computed values, being

TABLE XIIIa.

Average daily balance of protein and net energy available for growth.

No.	Average live weight lb.	Average daily increase in lb.		Balance available for growth			
				Computed		Actual	
		Whole period	1-week period	Protein lb	Net Energy Therms	Protein lb.	Net Energy Therms
1	281	·919	·816	·516	1·642	·277	1·185
2	298	1·112	1·074	·555	2·002	·284	1·588
3	260	1·068	1·005	·523	1·753	·286	1·298
4	260	·933	·859	·512	1·674	·278	1·221
5	188	1·113	1·048	·558	2·005	·292	1·542
6	245	·923	·861	·519	1·897	·291	1·217
AVERAGE	[illegible]	1·011	·943	·530	1·795	·285	1·338
7	469	1·239	1·114	·629	2·671	·312	1·452
9	468	1·264	1·160	·636	2·728	·319	2·501
10	418	·792	·722	·613	2·182	·325	2·285
11	382	·950	·895	·620	2·568	·337	2·325
12	439	·934	·843	·579	2·175	·302	1·922
AVERAGE	434	1·036	·947	·615	2·524	·319	2·287

derived from an overestimate of the actual digestion, considerably exceed the actual values in every case. The table also gives the average live weights and the estimated daily live weight increase. For the latter two sets of figures are given as already explained. It will be noticed that in most cases a high balance of net energy is associated with a high rate of live weight increase. Finally, the figures of this table can be used to calculate the net requirements of protein and net energy per lb. of increase. As we have two estimates for the rate of live weight increase there

will be two corresponding estimates for the requirements per lb. of increase. These final results are summarized in Table XIIIb. The average requirements per lb. of

Table XIIIb.

Net energy requirements per lb. increase.

—	Younger group		Older group	
	Net energy per lb. increase		Net energy per lb. increase	
	Computed	Actual	Computed	Actual
Based on increase during entire test . .	1·776	1·323	2·436	2·207
Based on increase during 14 weeks . .	1·903	1·419	2·665	2·415

increase may also be calculated in a slightly different manner, namely, by determining the requirements per lb. increase for each animal separately. The results obtained by this process are shown in Table XIVa. The averages obtained in this

Table XIVa.

Requirements per lb. increase calculated for each animal separately.

	No.	Based on live weight increase during entire test				Based on live weight increase during 14 weeks			
		Computed requirement		Actual requirement		Computed requirement		Actual requirement	
		Protein	Net energy	Protein	Net energy	Protein	Net energy	Protein	Net energy
Younger Group.	1 . .	·562	1·787	·301	1·290	·638	2·018	·330	1·453
	2 . .	·499	1·800	·255	1·883	·517	1·864	·204	1·432
	3 . .	·489	1·641	·268	1·215	·520	1·744	·285	1 292
	4 . .	·548	1·794	·298	1·308	·596	1·949	·324	1·421
	5 . .	·501	1·802	·262	1·386	·535	1·922	·279	1·479
	6 . .	·562	1·838	·310	1·351	·603	1·970	·338	1·448
	Average	·527	1·777	·288	1·322	·567	1·910	·305	1·421
Older Group.	7 . .	·508	2 155	·252	1·979	·565	2·397	·280	2 201
	9 . .	·508	2·150	·252	1·979	·549	2·352	·275	2 156
	10 . .	·774	3 133	·410	2·822	·840	3·438	·450	3 098
	11 . .	·653	2·698	·354	2·446	·693	2·864	·376	2 537
	12 . .	·620	2·320	·323	2 058	·687	2·580	·358	2 280
	Average	·611	2 495	·318	2·257	·668	2·726	·348	2·454

table do not quite coincide with the averages obtained in Table XIIIb. Therefore the means of these two sets of data has been taken to represent the requirements

per lb. of gain as found by our long period feeding test Our final results are stated in the accompanying table.

TABLE XIVb.

Digestible crude protein and therms of net energy required per lb. of increase.

—	YOUNGER GROUP				OLDER GROUP			
	COMPUTED		ACTUAL		COMPUTED		ACTUAL	
	Protein	Net energy	Protein	Net energy	Protein	Net energy	Protein	Net energy
Based on increase during entire test.	·525	1·777	·282	1·323	·602	2·465	·313	2·232
Based on increase during 14 weeks.	·565	1·907	·304	1·420	·660	2·696	·348	2·435

There are three points to note in this table :—

(1) The older group utilises decidedly more net energy to produce one lb. of gain than the younger group. This is true whether we compare computed or actual values.

(2) For reasons already given we believe that actual energy requirements per lb. of increase are somewhat underestimated if we use the increases during the entire test. The truer values derived from the live weight increases during 14 weeks are 1·420 therms and 2·435 therms actual net energy required per lb. increase for the younger and older groups respectively.

(3) The computed values derived from the increase during 14 weeks are 1·907 and 2·796 therms respectively. These are the quantities which must be fed in order that the smaller actual amounts may be digested. The computed values are therefore useful for the calculation of rations, while the actual values tell us the true consumption of net energy to produce one lb. of gain.

The nature of the gains made by growing cattle.

The last figures will be referred to again when existing data relating to the nature of the gains made by growing cattle have been considered. The materials of which the body increase consists vary with the age, breed and nature of food. The young animal puts on flesh containing much water, some protein and little fat. The fat content of the gain may, however, vary somewhat according to the nature of the food. An animal approaching maturity stores much more fat than protein and the water content of the gain decreases. The following data illustrating these

points have been taken from or calculated from figures given by Armsby[1] and Henry & Morrison.[2]

Authority	Age or live weight of animal	Composition of 1 lb. increase				Energy content of 1 lb. gain
		Water	Mineral	Protein	Fat	
Haecker . . .	100—200	·700	·040	·18	·08	·820
	200—300	·640	·040	·19	·13	1·040
	300—400	·590	·040	·19	·18	1·256
	400—500	·530	·040	·20	·23	1·508
	500—600	·510	·040	·18	·27	1·630
Soxhlet . . .	Calf 15 days old.	·624	·036	·18	·16	1·180
Jordan . . .	28 months old.	·396	·062	·136	·406	2·100
Watters Munford Throwbridge.	750 —1250	·374	·020	·12	·486	2·402
Fattening Expt. .	1250—1750	·178	·020	·052	·750	3·367
Laws and Gilbert .	48 months old.	·241	1·020	·077	·662	3·051

From these figures we have to decide what was the probable energy content of the gain made by our two groups of heifers.

In Waters fattening experiment the average value of the first 500 lb. increase was 2·402 therms per lb. and this included a period during which an appreciable amount of fattening occurred, whilst the ration given to our animals did not produce appreciable fattening as far as could be judged by appearance. Jordan's results for animals much older than ours is 2·1 therms per lb. Haecker's figures for animals of the size and age of ours are still lower. From these data we conclude that the energy content of 1 lb. of increase of our older group weighing 440 lb. per head could not have exceeded 2·4 therms per lb. and probably it was lower than this figure. Our results show that these animals consumed actually 2·435 therms per lb. of increase and on the whole though the evidence is indirect we believe that the energy content of the gain was less than the net energy available from the food digested.

For our younger group weighing 270 lb. per head the energy content of the gain should be according to Haecker 1·04 therms per lb. It might, however, have been more and we have no other data to check this figure. The actual net energy consumed per lb. of gain was 1·42. Whilst it does not seem likely that the energy content of the gain was as high as this figure, it is impossible to say definitely that the net energy consumed was greater than the energy content of the gain made. Armsby's estimates for the average energy content of gains by animals which were not fattened to a very great extent are very much higher than the figures quoted above. (Armsby Table IVa, p. 712.) He allows 1·680, 1·986, 2·292 and 2·904

[1] Armsby. *The Nutrition of Farm Animals.*
[2] Henry & Morrison. *Feeds and Feeding*, 17th ed.

therms per lb. gain respectively for animals aged 6, 9, 12 and 18 months. The same figures may be stated in another form thus :—

Age months	Average live weight	Energy content of 1 lb. gain
3- 6	220	1·680
6 -9	300	1·986
9- 12	360 .	2·292
12—18	480	2·904

According to these figures the energy content of the gains made by our two groups would be 1·833 and 2·721 therms per lb. gain respectively.

The Armsby feeding standard compared with Bangalore results.

Comparing the last figures with our experimental results we find that Armsby's estimates for the energy content of the gain coincide almost exactly with our computed net energy requirements per lb. (table XIV). The two sets of figures are :

— —	Younger group	Older group
Armsby's estimate of energy content per lb. gain	1·833	2·721
Bangalore computed requirements per lb. gain	1·907	2·696

But our computed requirements certainly do not represent the energy content of the gains made. Even if no energy at all were consumed in the elaboration of body substance (and according to our results with the older group there seems to be an indication of loss of energy) still the computed requirement is an overestimate of the actual requirement. Per lb. of increase our two groups required actually 1·42 and 2·43 therms respectively and we are justified in believing that the energy content of the gain could not have exceeded these amounts, while there is reason to believe that it may have been less. The practical result of these comparisons is, however, somewhat surprising. Armsby's estimate of the energy content of the gain is undoubtedly higher than the actual value of the gains made by our animals, but it agrees very closely with our figures for the computed net energy which would provide the actual needs. Therefore Armsby's standard for net requirements per lb. increase (Armsby table XIVa), though based on data for the energy content of the gain which do not hold for our animals, can be used for computing rations for our animals because the overestimate of the values of the gains compensates almost exactly for losses due to lower digestion, etc.

Armsby gives another table of rations for growing dairy cattle per head per day including maintenance (table IVb, p. 713). Assuming, as Armsby does, that the

requirement per lb gain increases regularly with increase in live weight we can calculate the requirements per head and day including maintenance from our own results The process is shown in the accompanying table to which is added, for the sake of comparison, Armsby's standard (table IVb)

TABLE XV

Estimated requirements per head per day

Live weight	Computed requirement per lb increase		Requirement for maintenance		Total for maintenance and increase		Total for maintenance and increase Armsby standard	
	Crude Protein	N E therms	Digestible protein	N E therms	Digestible crude protein	N E therms	Dig. protein	N E therms
200	54	1 [illegible]0	2[illegible]	2 [illegible]0	80	3 [illegible]	60	3 70
300	59	2 00		2 19	[illegible]	4 03	72	4 33
400	63	2 40	10	26	1 03	[illegible]6	80	5 [illegible]0
500	73	2 9[illegible]	1[illegible]	3 78	1 1[illegible]	6 [illegible]8	82	6 [illegible]0

The protein figures of Armsby refer to true protein and therefore are not comparable with ours As regards computed net energy requirement our figures are decidedly higher than Armsby's It should be pointed out that our estimated rations for growing heifers in table XV, though apparently based on an hypothetical maintenance requirement are really a restatement of our practical feeding results A reference to table XII shows that our heifers assimilated the following computed quantities daily during the long period feeding test

—	Live weight lb	Daily Assimilation	
		Computed protein lb	Computed net energy therms
Younger group	272	84	4 279
Older group	443	1 035	5 930

These figures agree with our values of table XV above For example, our younger group weighing 273 lb actually required 4 28 therms A 300 lb animal will require somewhat more than this The figure 4 69 is not excessive according to our result for the 272 lb heifers

Again our 443 lb. heifers actually consumed 5 93 therms The 500 lb animal must consume somewhat more It may be argued that the exterpolations required for calculation of the figures in table XV are unjustifiable as they are based on 2 experimental points only, but we have already shown that these points coincide with figures given by Armsby and our results in table XV are practically a restatement in somewhat different form of Armsby's table IVb. The fact is that the two tables,

IVa and IVb, represent two somewhat different standards of feeding or rates of growth. Our experimental results agree with table IVa, which may be employed, therefore exactly as we have done in table XV above, for calculating standard rations for growing heifers. It has to be noted here, however, that our older group may not have done full justice to their ration. Had they been somewhat more economical our results for the 400 and 500lb. animals would not have diverged to such an extent from table 4b. Owing to the doubt regarding the thriftiness of our older group it is impossible to say which of these two sets of figures is more likely to be generally applicable in India.

Estimation of the maintenance allowance from our experimental results.

The previous calculations have been based on a maintenance allowance of 6 therms per 1000 lb. live weight. In table XVI the balance of total digestible nutrients

TABLE XVI.

Nutrients required per lb. increase using Haecker's maintenance standard.

No	Average daily live weight increase	Nutrients required per lb.	
		Computed	Actual
1	·919	1·355	·784
2	1·112	1·516	1·032
3	1·068	·984	·752
4	·933	1·324	·769
5	1·113	1·871	1·005
6	·923	1·363	·835
AVERAGE	1·011	1·402	·863
7	1·239	1·904	1·657
9	1·264	1·905	1·662
10	·792	2·727	2·315
11	·950	2·395	2·053
12	·934	1·888	1·811
AVERAGE	1·036	2·164	1·899

available for growth have been calculated on the basis of the Haecker Savage maintenance allowance of 7·925 lb. total digestible nutrients per 1000 lb. live weight. On this basis the balance available per lb. of increase is low for both groups. Judging by figures for the energy content of the gains made by cattle generally the available energy as calculated in this table appears to be scarcely equal to the energy content of the gain made. The figures make it probable that too high a value has been assigned to the maintenance allowance. Further, it will be noticed that in the younger group a high rate of increase is associated with high actual requirement

per lb. increase, whilst a low rate of increase shows low requirement per lb. increase This is exactly what would occur if an excessive allowance were made for maintenance. The older group does not show this regularity, but in this case, the balance available for production is much greater and would be less affected by alteration of the maintenance figure. It is not intended to lay stress on these figures but they seem to indicate that 6 therms per 1000 lb. is a better estimate than 7 therms for animals weighing 250 to 450 lb.

Comparison of the Wolff Lehmann feeding standard with the Bangalore results.

The Wolff Lehmann Standard for growing dairy cattle is as follows[1] :—

Average Age months	Average live weight lb.	Digested protein lb.	Total Digestible Nutrients lb.	Bulk (dry matter) lb.
1—3	150	·60	3·24	3·45
3—6	300	·85	5·43	7·20
6—12	500	1·05	7 82	13·50
12—18	700	1·22	10·65	18·20

From these figures the standard requirements of our heifers have been calculated. The results of the calculation are shown below together with our experimental results.

—	Average weight	Computed		Bulk
		Digested protein	Total digestible nutrients	
	lb.	lb.	lb.	
Bangalore results	272	·842	4·748	8·182
	443	1·035	6·704	11·682
Wolff Lehmann results	272	·82	5·00	6·5
	443	1·02	7·20	11·7

The computed protein agrees well with the standard requirement. Bulk consumption for the older group is normal, for our younger group it is seen to be abnormally high. This remarkable figure is undoubtedly due to the fact that our animals were undersized at the commencement of the test. They were old for their weight and had developed more stomach capacity than body substance. In computed digestible nutrients both our groups received distinctly less than the standard allow-

[1] Henry and Morrison. *Feeds and Feeding*, 17th ed.

ance, which accordingly is intended for more rapid growth than that attained by our heifers. The bulk of ration consumed by our animals was already so large that it could scarcely have been increased appreciably even if only silage had been fed as roughage. To increase the rate of growth and to provide the full Wolff Lehmann Standard allowance of total digestible nutrients it would have been necessary to feed a higher proportion of concentrate. We obtained reasonably good growth with rations containing a higher proportion of roughage and somewhat less total digestible nutrients than the amounts recommended in the Wolff Lehamann standard for growing heifers. It may be noted finally that our ration is somewhat below the Wolff Lehamann standard and distinctly higher than Armsby's standard of table 4b.

Summary.

1. Digestion attained by individuals of two groups of heifers varied somewhat widely, but the digestion capacity of the older group was on the average distinctly higher than that of the younger group.

2. The difference in digestion between the two groups is only partly due to difference in age. A higher consumption per 1000 lb. live weight and a higher proportion of hay consumed by the younger group probably account for part of the difference.

3. The use of American digestion coefficients for computing the digestibility of our rations gives misleading results.

4. Comparing actual digestion with the digestion attained by mature bullocks on the same foods at Bangalore it is found that the carbohydrate digestion is 10 per cent. below normal in the younger group and 3·4 per cent. below normal in the older group.

5. The computed requirements per lb. gain were found to be 1·907 and 2·696 therms for the younger and older groups respectively.

6. The Armsby standard of requirements, though based on data for the energy content of the gain which does not hold for our animals, can be used for computing rations for our animals because the overestimates of the values of the gains compensate almost exactly for losses due to lower digestion etc. On the whole our requirements for growing animals are higher than Armsby's figures.

7. Compared with the Wolff Lehmann feeding standard our heifers utilized the standard amount of protein, and less than the standard amount of total nutrients. The bulk consumed by the older group was normal. The younger group consumed an abnormally large bulk.

Acknowledgments

We are greatly indebted to Mr. Smith, Imperial Dairy Expert, for the facilities afforded us in carrying out this enquiry. The animals, the stalls and the foods were provided by him. We have also to thank the Physiological Chemist's staff who carried out the analysis connected with the work.

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A Study of Absorption of Moisture by Soils

BY

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CONTENTS.

A STUDY OF ABSORPTION OF MOISTURE BY SOILS.

BY

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(Received for publication on 1st May 1926.)

The texture of a soil is an important factor in determining the growth of plants. On the size of the soil particles depend the tillage properties, the air and water movements within the soil, the functioning of the organisms present and thus also the elaboration of plant food material. The whole system of agriculture, including cultural operations and choice of crops, has to adapt itself to soil texture of the fields which are to be dealt with.

Methods of mechanical analysis of soils have been devised whereby the amounts of particles of different sizes can be determined. While a proper interpretation of the results of such estimations is of value in judging the cultural possibilities of soils, the methods of analysis are themselves tedious and time-absorbing. Any other convenient process whereby the texture of soils can be judged will therefore prove to be of great utility.

Of the "separates" or fractions of different-sized particles, "clay", which possesses the smallest dimensions (less than 0·002 mm. diameter), is of great significance. The finer parts of clay include the ill-defined group of materials known as the soil colloids. In the opinion of early workers, only a small fraction of clay is colloidal, but some recent researches (*cf.* Robinson and Holmes,[1] Joseph[2]) suggest that the clay fraction of the mechanical analysis is nearly all colloidal. Joseph [3] has shown that practically the whole of the clay fraction can be obtained in the colloidal state. On account of their small size, clay particles possess an enormous superficial area. Hence soils rich in clay exhibit high activities in connection with all surface phenomenon such as absorption of moisture.

[1] *U. S. A. Dept. Agri., Bull.* 1311 (1924).
[2] *Rept. Soudan Chemist* (1923), 22.
[3] *Soil Sci.*, 20 (1925), 89.

Moisture absorption. It has been maintained that the determination of hygroscopic capacity of soils is of great significance since it presumably gives a constant for the soil depending on its internal surface, the influence of which on soil conditions, especially as related to plants, is extremely important. As early as 1859 Hilgard began a study of this factor and he defined " hygroscopic coefficient " as the percentage of moisture which dry soil can absorb when exposed to a saturated atmosphere.

The process of determining hygroscopicity of soils seems at first sight to be a very simple one. Considerable care has, however, to be taken in order to obtain accurate and strictly comparable results. The temperature has to be kept constant, as the absorption varies with the temperature and as, moreover, local variations of temperature are likely to cause a deposition of free water (dew) on some of the soil particles. For the same reason undue disturbance of the atmosphere in the absorption chamber should be avoided. A very thin layer of soil should be used and the time of exposure should be sufficiently long to ensure a near approach to conditions of equilibrium. In practice, it is more convenient to work at atmospheres of lower humidity than saturation point. The facts that the soil water contains dissolved substances and that the surface of this water in the capillary interstices possesses a concave curvature indicate that the aqueous vapour pressure of soils is always lower than that of pure water. Hence from theoretical considerations it follows that when a soil is exposed, as in Hilgard's method, in a closed atmosphere containing freely evaporating distilled water, there will be a continuous condensation from the water to the soil. Mitscherlich's method of exposing the soils to an atmosphere in equilibrium with 10 per cent. sulphuric acid is thus more convenient than Hilgard's method. Robinson[1] used a 2 per cent. sulphuric acid solution as the humidifying agent, while Puri, Crowther and Keen [2] advocated the use of 43·4 per cent. sulphuric acid which brings about a humidity of 50 per cent. in the atmosphere.

Mechanical composition and absorption by soils. A review of the theory about the correlation between absorptive capacity of soils and their fertility is to be found in Alway, Kline and McDole's paper.[3] Here only a brief reference will be made to the relationship between hygroscopic capacity and mechanical composition of soils.

In Hilgard's opinion " the hygroscopic coefficient " yields a datum which bears a definite ratio to the clay and humus content, and Mitscherlich utilized his own hygroscopicity figures for the determination of colloids in soil. A simple mathematical formula was evolved by Briggs and Shantz [4] tracing the connection between hygroscopic coefficient and mechanical composition. Later Alway and Rost[5]

[1] *Jour. Phys. Chem.*, **26** (1922), 647.
[2] *Jour. Agri. Sci.*, **15** (1925), 68.
[3] *Jour. Agri. Res.*, **11** (1917), 147.
[4] *U. S. A. Dept. Agri.*, *Bull.* **230** (1912).
[5] *Soil Sci.*, **1** (1916), 405.

introduced a refinement in the Briggs-Shantz equation by slightly altering the constants. The subject was studied by Novak[1] who observed that soils having the same hygroscopicities may have entirely different mechanical composition, but that for practical purposes, a high proportion of clay particles is accompanied by high hygroscopicity. Further Oden noted that although the values obtained for a series of clay soils were not proportional to the soil particle surface, the hygroscopic coefficient might serve for empirical comparisons of soils known to be of the same type. It was found by Thomas[2] that the ratios of hygroscopic moisture agreed closely with the ratios of surface, as determined by mechanical analysis, of the particles larger than about 0·1—0·25 micron radius, disregarding the smaller material. In the opinion of Anderson, Fry, Gile, Middleton and Robinson[3], not less than 95 per cent. of the total absorption of the soil is due to the colloidal part, and Robinson[4] observed that the amount of water absorbed by the soil may possibly show the amount of colloids present more accurately than the absorption of dye or ammonia.

Specificity of soil colloids. The constancy of the specific water absorption capacity of soil colloids has been a debated question. Robinson[4] noted that samples of the colloid matter extracted from 34 samples of soils which differed widely in texture, origin, mode of formation and chemical composition showed a relatively constant absorption of water. Joseph[5], on the other hand, maintains that on correlating Robinson's figures about absorption of moisture with chemical composition of the colloids, there can be traced a relationship, which is, however, often obscured in individual cases. It has been pointed out by Hardy[6] that the Briggs-Shantz relationship connecting maximum water-retaining capacity with hygroscopic coefficient fails when applied to siliceous colloids, and that laterite soils, in which the colloid content is composed mainly of alumina and ferric oxide hydrogels, also do not obey the equation, the variation being in the opposite direction in the latter case. Middleton's[7] study of binding power and Anderson's[8] investigation of heat of wetting as well as Joseph's own experiments on imbibitional-water-holding capacity and rate of evaporation yield information about the relation between the properties and the chemical composition of soil colloids. Hardy's results show that variations in the shrinkage coefficients of soils of similar colloid content, but belonging to different geological types, are probably due to specificity in soil colloids. The fact must, however, not be overlooked that, as Hardy points out, the apparent anomalies in the properties of the soil hydrogels have also been explained by other theories. The irregularities are perhaps to be attributed to physico-chemical

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1 *Landw. Jahrb.*, **50** (1917), 454.
2 *Soil Sci.*, **17** (1924), 1.
3 *U. S. A., Dept. Agri., Bull.* **1122** (1922); also *Bull.* **1193** (1924).
4 *Jour. Phys. Chem.*, **26** (1922) 647.
5 *Soil Sci.*, **20** (1925), 89, *cf.* also Joseph and Hancock, *Jour. Chem. Soc., Trans.*, **125** (1924), 1888.
6 *Jour. Agri. Sci.*, **13** (1923), 243; *ibid*, 340.
7 *Jour. Agri. Res.*, **28** (1924), 499.
8 *Jour. Agri. Res.*, **28** (1924), 927.

changes of environment induced by their genesis and history rather than to chemical composition. Viewed in this aspect the theory is more in keeping with the fundamental conception of colloids as matter in a particular *state* rather than distinct *kinds* of matter of varied individuality. Recent researches on gels, both inorganic and organic, are rapidly leading to a recognition of the fact that specificity in these colloids is conditional and structural rather than absolute.

The subject is complicated by the difficulty of separating the numerous and highly complex soil colloids in their entirety and without any of their properties being modified. It is thus wellnigh impossible to conduct an accurate study of their functions and to find out how these are related to their chemical composition. It must also be remembered that these colloids are constantly suffering changes as a result of cultural practices and the physical, chemical and biological changes going on in nature.

Humus and absorption. The important function of the organic matter of the soil in increasing its hygroscopic quality has been recognised by Hilgard,[1] Loughbridge[2] and other workers. Alway and McDole,[3] however, found that this influence is too slight to be detected, a change of even 100 per cent. in the organic content being without distinct effect on the moisture absorbing property of soil. Recently McCool and Wiedemann[4] have, in the course of their study of certain organic soil profiles, observed that the capacity of these soils to hold water unfree depends not upon the organic content but upon the stage of decomposition and nature of the materials.

The influence of temperature. There has been a controversy as regards the in fluence of temperature on the moisture absorption by soils. The experiments of Lipman and Sharp[5] and of Alway, Kline and McDole[6] support Hilgard's statement that hygroscopic coefficient increases with the temperature. On the other hand, Patten and Gallagher's results[7] and the recent paper by Puri[8] support the views of Knop and other workers who found a lower absorption at higher temperatures. Puri attributes the disputes about diminution of hygorscopic coefficient with increasing temperature to the exposures of previous workers being too short and to the fact that in the early stages the *rate* of moisture absorption increases with increasing temperature.

In the course of the present series of experiments a study was undertaken to find out the relation between the clay content and the absorptive capacity of soils and of the influence of temperature on the moisture absorption.

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[1] *Jour. Amer. Chem. Soc.*, **16** (1894), 4; "Soils," (Ed. *1906*), 194.
[2] *Rept California Sta.*, 1892-93-94, 76.
[3] *Soil Sci.*, **1** (1916), 197.
[4] *Soil Sci.*, **18** (1923), 117.
[5] *Jour. Phys. Chem.*, **15** (1911), 709.
[6] *Jour. Agri. Res.* **11** (1917), 147.
[7] *U. S. A., Dept. Agri., Bur. Soils, Bull.* **51** (1908).
[8] *Jour. Agri. Sci.*, **15** (1925), 272.

*Soils used.** Eleven samples of soil were utilized for this study. The first five belonged to the Madras Presidency. Of these three, *viz.*, S1 a black cotton soil, S2 a red laterite soil, and S3 a garden soil, came from Coimbatore. S4 was a hilly soil from one of the planting districts, while S5 was a heavy paddy soil from the deltaic area (Manganallur).

There were three samples from Bengal. S6 was a red laterite from Dacca while S7 was a tobacco soil from Rungpore. S8 was an abnormal soil collected at Siliguri. It was black in colour and was rich in plant débris.

Two samples belonged to the United Provinces. S9 was a loamy soil (*mar*) from Orai and S13 was a highly sandy soil (*bhur*) from Mainpuri.

The last sample S15 was a heavy clay soil (*Sane-putchi*) from Mandalay, Burma.

It will be noted that the above list included samples of all the main types into which Indian soils are divided (Leather[1]), *viz.*, the Indo-Gangetic alluvium, the Madras soils, black cotton soils, and laterite soils. Two of the samples (*viz.*, S8 and S13) were of an unusual nature.

Determination of clay. The mechanical analysis was carried out by the Coimbatore method elaborated by Dr. W. H. Harrison. As the details of the process do not appear to be known to outside laboratories, a brief description is appended herewith.

Ten grams of soil are vigorously boiled for 15 minutes with 250 c.c. distilled water in a 500 c.c. conical flask. The whole is then transferred to a beaker, the liquid made up to a height of 10 cm., stirred and allowed to settle. After 24 hours the suspension is decanted off, the residue is put back into the flask with about 250 c.c. water and the whole vigorously boiled for 5 minutes. The contents are then transferred to the beaker, again made up to 10 cm. height, shaken up and allowed to settle for 24 hours. These alternate operations of boiling with water and settling are repeated, till no further appreciable amounts of clay are obtained.

In the English method of mechanical analysis the soil receives a preliminary treatment with acid, in order to loosen the particles in any aggregates or compound particles where chalk or humus forms the cement, and ammonia is afterwards used to complete the dissolution of the humates and improve the deflocculation. As has been pointed out by Joseph and Martin[2], this treatment with acid introduces a complication, because the dilute acid is undoubtedly capable of dissolving material which, so far as size of particles is concerned, should be considered clay. In the Coimbatore method the use of chemicals is avoided, the disintegration of the compound particles being brought about with the help of vigorous ebullition. The grading of size effected by the Coimbatore method thus closely corresponds to the texture of the soil under actual field conditions.

* The thanks of the writers are due to the Agricultural Chemists of Madras, Bengal and Burma and the Deputy Director, Central Circle, United Provinces, for their kindly supplying these soils.

[1] *Agri. Ledger No.* 2, (1908).

[2] *Jour. Agri. Sci.*, 13 (1923), 49.

A microscopic examination of the 24 hours sediment showed that the particles have diameters $<0{\cdot}002$ mm.

Determination of humus. This was carried out by Huston and McBryde's method.

Dye absorption. Solutions of various dyes were experimented with, but the method was found to be rather unsatisfactory. The soil suspensions were often difficult to settle, and at times an alteration of the tint of the dye solution was brought about by the action of the soil. Fortuitous precipitation of some dyes was also at times likely to take place. The choice of an effective dye which would serve to determine the clay content of all soils is still an unsolved problem.

The retention of dyes follows the exponential formula generally applicable to absorption phenomena. In an experiment where a solution of methylene blue was percolated through a column of soil, the distribution of the dye in the different layers of soil was found to obey a log-log curve.

An account of the experiments on dye absorption is given in the Appendix.

Moisture absorption. As the results of the hygroscopic determinations depend on the experimental procedure adopted, a description of the actual process followed is given here.

Preliminary experiments with pure water as the humidifier showed the desirability of using a liquid which gave a lower vapour tension. Trials were next made with aqueous solutions of glycerine of various strengths, as a result of which it was decided to use a solution containing 25 c.c. pure glycerine per 100 c.c. An addition of a small quantity of mercuric chloride (0·1 grm. per 100 c.c.) was made in order to prevent fungoid growths in the liqud.

Particular attention was given to the maintenance of a steady temperature. The thermostat in which the dishes were kept was provided with extra insulating material in the shape of cork mats and waddings of cotton wool on the top and sides. The whole apparatus was placed in a protected corner of a room free from disturbing currents of air. The variation in temperature was found to be $\pm$ 0·5°C.

The glass vessel which served as the absorption chamber was wholly coated on the outside with a thick layer (about $\frac{1}{8}$ inch) of asbestos paste. By this means, sudden local variations of temperature within the chamber. likely to occur at any time (*e.g.*, when the door of the thermostat was opened) and consequent liability of deposition of dew over the soils, were prevented. Two grammes of soil were exposed in the form of the thin layers in small petridishes of 4 cm. diameter.

Where the temperature used was higher than the atmospheric one (*i.e.*, in all cases except at 20° C.) the dishes containing soils were first kept in the absorption chamber inside the thermostat till they attained the temperature of the thermostat. It was only after the temperature condition of the system had become constant that the vessel containing glycerine solution was quickly introduced inside the chamber which was immediately closed again and the door of the thermostat shut. By this means the temperature of the soils was never at any time lower than that of

the evaporating liquid, and there was no fear of condensation of free water on the soils.

For the experiments at 20°C., an incubator cooled with ice was used. The variation in temperature was $\pm$ 1°C. It was noticed in this instance of working at a temperature lower than that of the atmosphere that the chances of deposition of dew were greater than in the other cases where the temperature of the absorption chamber was higher than the atmospheric temperature. In this case, the vessel containing glycerine was first put in the absorption chamber and the soils were introduced later, only when the temperature was reduced to 20°C.

At the end of 5 days' exposure, the dishes were quickly covered and weighed. They were again put back in the chambers and weighed every alternate day till conditions of equilibrium have set in. They were then dried at 100°C. and their dry weight ascertained. The water absorbed by a unit weight of oven dry soil was then calculated.

Results. The figures obtained are recorded in Table I and are graphically represented in Chart 1.

TABLE I.

Absorption of Moisture by Soils.

No.	Description	Humus per cent.	Clay per cent.	Milligrams water absorbed by 1 gram dry soil								
				20°	25°	30°	36°	40°	45°	50°	55°	60°
S1	Black cotton soil, Coimbatore	0·035	22·72	111	88	80	80	80	76	73	70	70
S2	Red soil, Coimbatore	0·011	14·25	62	50	44	43	43	36	40	35	32
S3	Garden soil, Coimbatore	0 050	32·49	161	124	115	114	116	110	110	108	107
S4	Hilly soil, Planting District	0·039	19·42	90	67	59	59	56	53	53	44	46
S5	Paddy soil, Manganallur	0·014	34·31	147	120	114	112	110	106	107	101	93
S6	Red laterite soil, Dacca	0 012	26·58	108	81	69	69	71	64	65	58	62
S7	Tobacco soil, Rungpore	0·021	3·87	22	13	13	10	11	8	10	9	8
S8	Black soil, Siliguri	0·064	3·00	38	31	24	26	25	21	21	20	18
S9	Mar soil, Orai	0·010	19·04	96	77	72	69	70	66	64	56	56
S13	Bhur soil, Mainpuri	0·004	3·14	10	6	5	4	5	3	4	3	3
S15	Saneputchi soil, Mandalay	0·013	23·13	104	81	73	73	75	71	66	65	63

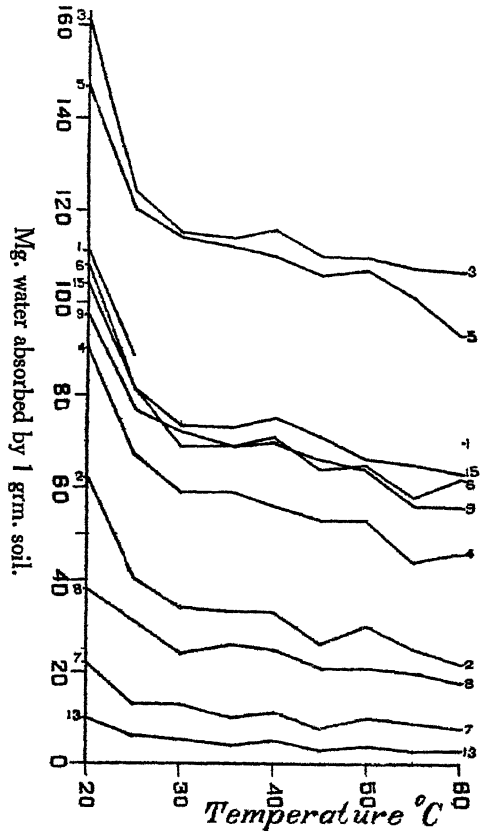

CHART I.

Showing the amounts of moisture absorbed at different temperatures. The small numerals marked against the individual curves indicate the numbers of the soil samples.

The above results indicate that the absorption depended on the clay content of the soil. On plotting the values of percentages of clay (c) against milligrams of water absorbed (w) at the individual temperatures, it was noted that the curve obtained is of a simple exponential nature, so that

$$w = \text{const.} \times c^{k}\text{—}$$

where k is another constant, whence it follows that

$$\log w = a + k \log c,$$

where a and k are constants.

TABLE II.

Relation between Moisture Absorption and Clay Content.

No.	Description	Log c	Log W 20°	25°	30°	36°	40°	45°	50°	55°	60°
S1	Black cotton soil, Coimbatore	1·356	2·045	1·944	1·905	1·901	1·905	1·883	1·861	1·846	1·846
S2	Red soil, Coimbatore	1·153	1·790	1·696	1·640	1·629	1·637	1·557	1·606	1·547	1·509
S3	Garden soil, Coimbatore	1·512	2·206	2·094	2·062	2·056	2·068	2·043	2·043	2·032	2·028
S4	Hilly soil, Planting District	1·288	1·955	1·824	1·772	1·769	1·750	1·723	1·721	1·641	1·666
S5	Paddy soil, Manganallur	1·535	2·167	2·078	2·056	2·049	2·042	2·025	2·014	2·004	1·966
S6	Red laterite soil, Dacca	1·425	2·034	1·906	1·840	1·841	1·850	1·808	1·813	1·767	1·794
S7	Tobacco soil, Rungpore	·588	1·335	1·099	1·101	1·003	1·035	·906	·983	·957	·906
S8	Black soil, Siliguri	·477	1·576	1·498	1·388	1·423	1·393	1·312	1·320	1·297	1·251
S9	Mar soil, Orai	1·280	1·982	1·886	1·856	1·837	1·845	1·819	1·807	1·746	1·751
S13	Bhur soil, Mainpuri	·497	1·016	·805	·653	·545	·654	·493	·546	·399	·440
S15	Saneputchi soil, Mandalay	1·364	2·015	1·909	1·861	1·864	1·877	1·849	1·821	1·815	1·798

c=per cent. clay ; w=milligrams water absorbed by 1 grm. dry soil.

Table II shows the values of log *w* and log *c*. When the logarithms of the amounts of moisture absorbed at a definite temperature are plotted against logarithms of clay content, they all (except in the case of the two soils S8 and S13) lie on a straight line, as will be seen from an examination of Charts 2-5, where there are plotted the values of log *c* and log *w* for temperatures 20°, 25°, 45° and 60°C. The same relationship holds in the case of the other temperatures tried, but the above four charts suffice to illustrate the general type of the curves obtained.

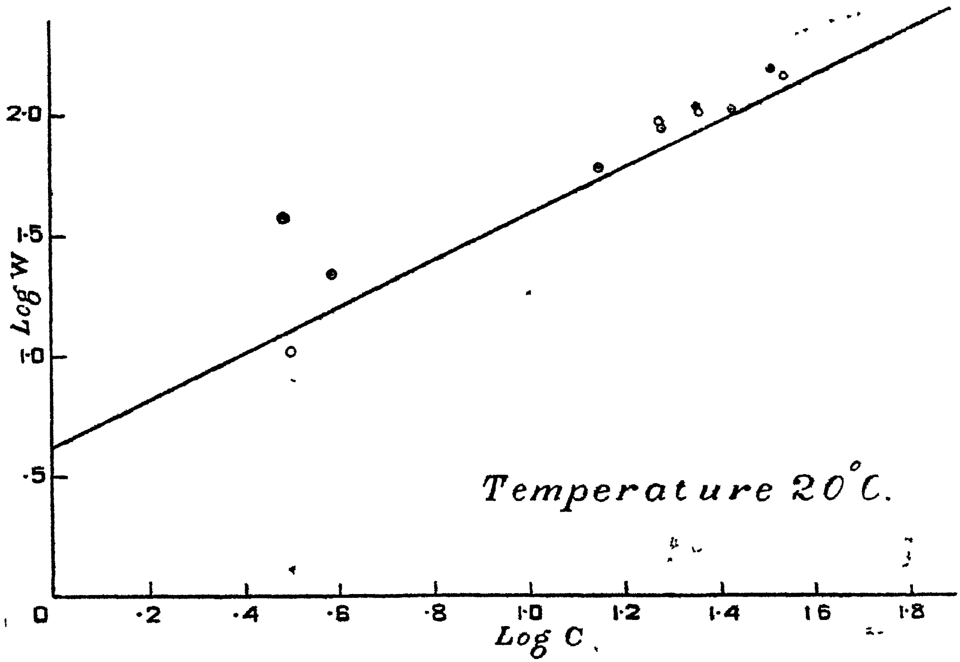

CHART 2.

Log w-log c curve at 20° C.

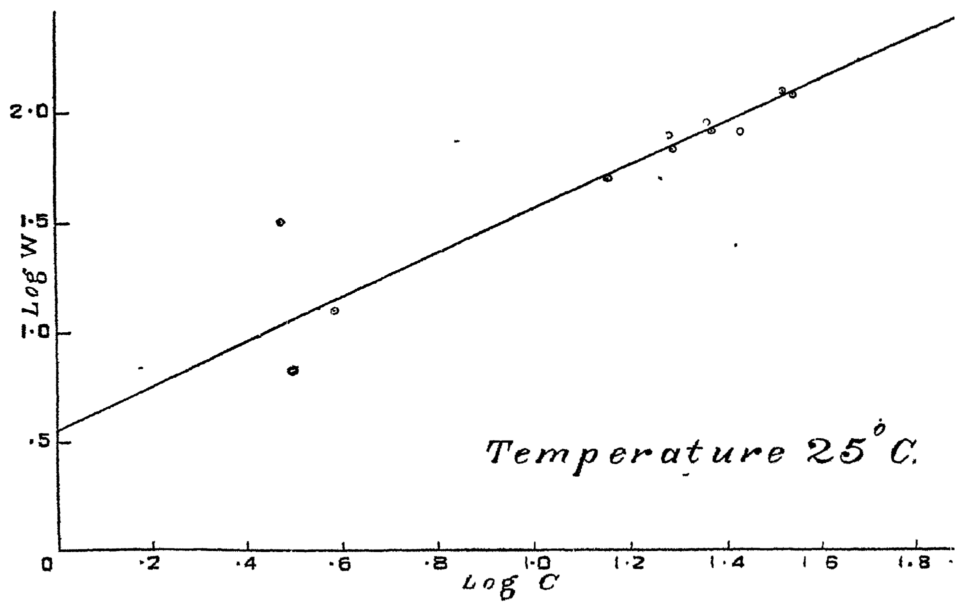

CHART 3.
Log w-log c curve at 25° C.

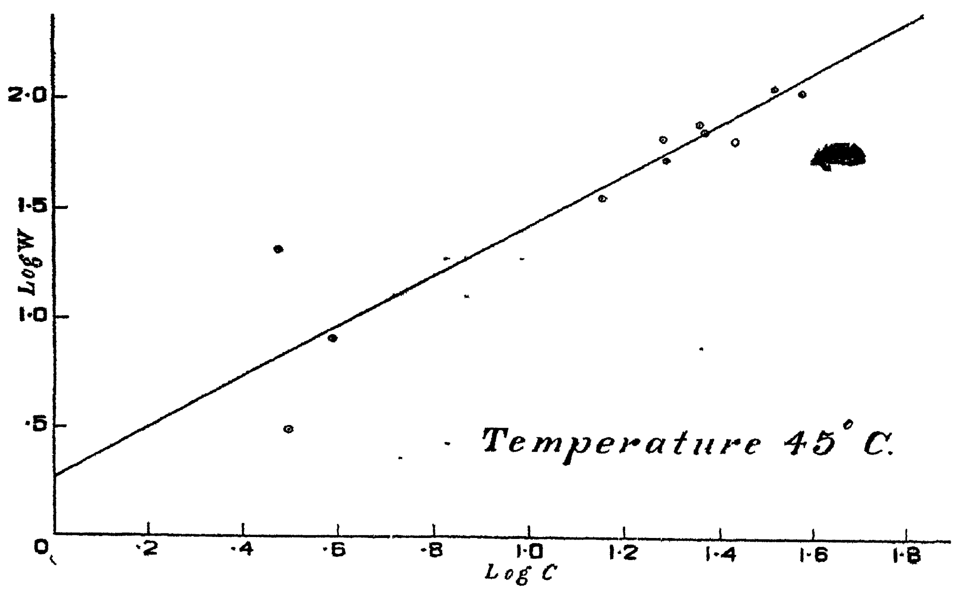

CHART 4.
Log w-log c curve at 45° C.

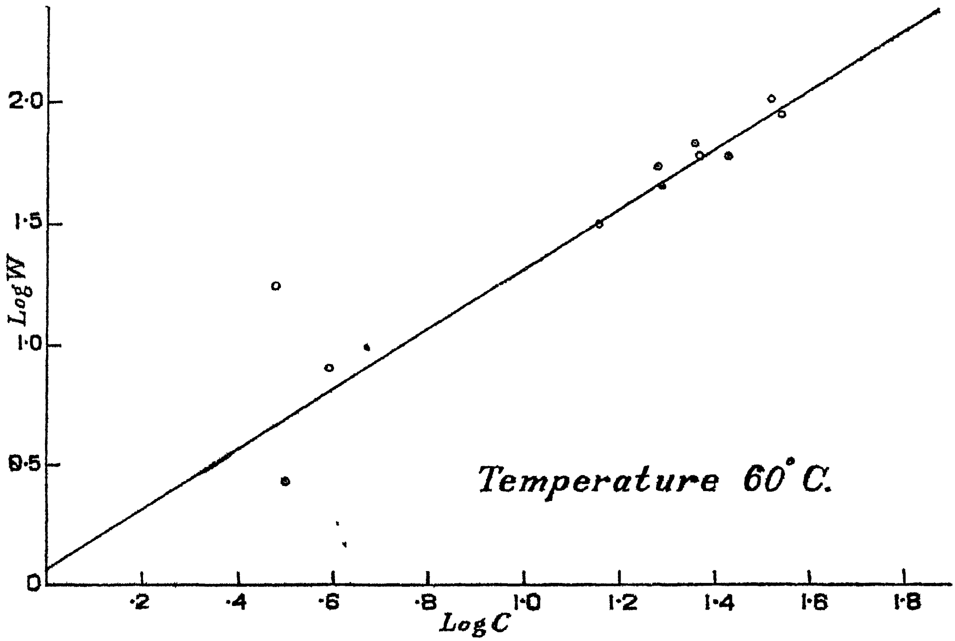

CHART 5.

Log w-log c curve at 60° C.

This simple relation between log w and log c is remarkable in view of the fact that the samples used represent widely varying types. The phenomenon is interpreted to lend additional support to the concept of a colloidal complex of inorganic and organic compounds enveloping the mineral particles of soil, which has been postulated and which has served to explain satisfactorily various soil moisture relationships and phenomena of flocculation, shrinkage and other properties (*cf.* Keen[1], Fisher[2], Wilsdon[3], Thomas[4], Comber[5], Hardy[6], etc.). On this view the soil grains are enlarged by being coated with a jellylike covering of colloidal material with a moisture gradient from the core to the outside, and it is this outer coating which is active in absorption phenomena.

[1] *Jour. Agri. Sci.*, **10** (1920). 44 ; *cf.* also *ibid*, **6** (1914), 456 and *ibid*, **11** (1921), 432.
[2] *Jour. Agri. Sci.*, **13** (1923), 120 ; **14** (1924), 204 ; also *Roy. Soc. Proc.*, **103**A (1923), 139, 664.
[3] *Mem. Dept. Agri. India, Chem. Ser.*, **6** (1921), 154.
[4] *Soil Sci.*, **17** (1924), 1.
[5] *Jour. Agri. Sci.*, **10** (1920), 425 ; **11** (1921), 451 ; **12** (1922), 372.
[6] *Jour. Agri. Sci.*, **13** (1923), 243.

Deviations from the simple logarithmic relationship were noted in the case of two soils. One is a sand from the United Provinces where the values are lower than the calculated figures. In this case it is quite conceivable that the colloidal coating over this highly siliceous material would function differently from that existing in the normal agricultural soils. The other exception refers to an organic soil from Bengal which shows a high absorption. This soil is rich in organic matter. The particles are stained black and it is apparent that the state of decomposition of the plant residues in this soil is quite distinct from that of the organic matter of the usual cultivated soils. It is to be expected that the hydrophilous surface of the organic constituents would be determined by the extent and orientation of the humification processes going on within the soil. In this connection, attention may be drawn to Comber's[1] amplification of the colloidal theory of the constitution of clay earlier emphasized by Rohland and others. It is the relative dominance of the properties of the emulsoid surface over the properties of the suspensoid core of the particles which determines the absorptive function of the soil. In the case of the usual agricultural soils the colloids present, both inorganic and organic, are of a roughly similar type and the absorption therefore approximates to a simple exponential formula. Where, however, the colloids are of an unusual nature, deviations occur. For instance, the colloids in the highly sandy (*bhur*) soil (S13) and also those present in organic soil (S8) function differently, the former being less absorptive than usual, whereas the latter are more active than is normally the case. Reverting in particular to the organic matter, it seems that as all agricultural soils of the ordinary type contain organic residues of an approximately similar character and as the trend of their decomposition processes is of the same nature, the specificity in the action of the organic contents of soils is usually masked. This holds in the case of the majority of the soils examined in the present instance and similar has also been the experience of Alway and McDole to whose results a reference has been made earlier. Where, however, the organic contents of the soil are of an unusual nature, their specific action is rendered apparent. It is to be remembered that the absorption is regulated by the active superficial area of clay and humus, the coarser mineral particles not counting for much because of their relatively small surface. The atomic packing in the surface of these two active soil constituents is no doubt open to mutual influence of each other and the absorption capacity is bound to be modified by the resultant differences in dispersion.

It thus follows that where the correlation between clay content and hygroscopic capacity is anomalous, the soils concerned are likely to be abnormal from the cultural point of view. The determination of the relationship is therefore likely to be useful in determining the agricultural value of soils.

[1] *Jour. Soc. Chem. Ind.*, **41** (1922), 77T.

As to the variation of absorption with variation of temperature, the results show that there is a general decrease of hygroscopicity as the temperature is raised. In fact, in the equation

$$\log w = a + k \log c,$$

the constants a and k seem to vary regularly with the temperature, their values agreeing, except in the case of the set at temperature of 20°C., to the following formulæ

$$a = b + ct$$

and $$k = m + nt,$$

where t = temperature in degrees Centigrade, and b, c, m and n are constants having the values, $b = 0{\cdot}90$, $c = 0{\cdot}014$, $m = -0{\cdot}825$ and $n = 0{\cdot}0072$. At 20°C, although the observed values of log w are higher than those calculated from the above formulæ, the log w—log c curve is still a straight line and is parallel to the straight line calculated from the above constants. No explanation is advanced to account for this phenomenon observed at 20°C. The regulation of temperature was rather troublesome in this set of experiments which were carried out in summer with the help of cooling by ice. It is to be noted that prevention of dew deposition becomes increasingly difficult as the temperature is lowered below the atmospheric temperature. All the other determinations were made at temperatures higher than that of the atmosphere and the temperature regulation was under easier control. For practical purposes, it is more convenient to carry out determinations at a temperature a little higher than that of the atmosphere, *e.g.*, 30°—40°C.

Conclusions.

1. Of the eleven samples examined, nine soils of widely varying types, when exposed to an atmosphere in equilibrium with a 25 per cent. solution of glycerine in water, absorb quantities of moisture which are exponential functions of their contents of clay. The equation $\log w = a + k \log c$, signifies this phenomenon, where w represents milligrams of water absorbed by 1 gram of dry soil, and c indicates the percentage of clay as determined by mechanical analysis, while a and k are constants.

2. The determination of the hygroscopic capacity of the ordinary cultivated soils yields an useful single-valued expression of the relative fineness of texture and serves as a means of comparing different samples of such soils.

3. The determinations, which were made at 20°, 25°, 30°, 36°, 40°, 45°, 50°, 55° and 60°C., show that as the temperature increases, the moisture absorption capacity of soils decreases. The figures indicate that, with one exception, the constants a and k are linear functions of temperature. The only exception is that at 20°C. where the observed figures are higher than those calculated, but the log w-log c curve is still a straight line running parallel to the curve of calculated values.

4. The eleven soils under examination included a siliceous soil from the United Provinces and an organic soil from Bengal. The former soil gave values lower than those calculated from its clay content, while the latter showed an absorptive capacity higher than that corresponding to the amount of clay contained in it.

5. The specificity of the inorganic and organic gels existing in the soil is usually masked, the major part of the colloids present in ordinary soils being of similar effectiveness. The difference in their nature is, however, manifested in the case of unusual types of soil. Instances are afforded by the abnormal results obtained by the two soils referred to above.

6. An examination of the correlation between the clay content and the moisture absorbing capacity will thus serve as an useful indication of the type of colloids present in a soil and yield information about its cultural possibilities.

7. The colloids of the soil are highly complex and are, moreover, suffering endless alterations as a result of the natural processes constantly going on inside the soil. The absorption of moisture is a relatively simple phenomenon which can be utilized for investigating the colloids at any particular time and under definite conditions. As such, the subject is worthy of further studies.

ACKNOWLEDGMENT. This work was carried out in the Chemical Laboratory of the Agricultural Research Institute, Pusa, and it is our pleasant duty to tender thanks to Dr. W. H. Harrison, Imperial Agricultural Chemist, for valuable help, especially in the mathematical interpretation of the results. We further acknowledge the assistance which has been rendered by Mr. U. Sen Gupta in carrying out some of the estimations.

APPENDIX.

Preliminary experiments were at first made with dye solutions of different strengths, mainly 0·005 and 0·05 per cent., solutions of intermediate strengths being also used in certain instances. The dyes included acid fuchsine, acid green, cardinal, chlorazol, chlorazol blue, clayton yellow, congo red, fuchsine, gentian violet, induline, malachite green, methyl blue, methyl green, methyl red, methyl violet, naphthalein black, naphthalein blue, navy blue, nigrosine, primuline, tartrazine and toluylene blue. Weighed quantities of soils, both "air dry" and freshly collected from fields, were shaken up in stoppered glass bottles and the liquids were then allowed to settle for 24 hours. The actual amounts of soils used varied with the nature of the soil and their moisture contents.

In the case of some dyes, the absorption was of an unsuitable nature, being too low or else very high. A few of the dyes were, moreover, very liable to fortuitous precipitation, being deposited on the sides of the bottles and giving rise to the formation of a layer of deeper tinted particles on the surface of the settled soil. Very often the soil suspension was extremely difficult to settle, so that the subsequent examination of their colour could not be carried out with accuracy. Again, an alteration of tint was likely to be effected by the soil, the dye being selective in its action on the acidic and basic constituents of the soil and an undesirable change in the hydrogen-ion concentration being thus brought about. An attempt was made to effect an improvement by the addition of different amounts of acids and alkalies to the dye solutions, but neither this procedure nor the previous treatment of the dye solution with some soil of the same type as the one under examination, proved quite effective. It must be remembered that these additions as well as the use of sodium chloride, to which latter a reference would be made subsequently, are likely to produce alterations in the soil colloids. But after all, as the object is to find out a comparative method, the effect of these additions was included in the tests.

As a result of all these experiments, it was decided to restrict the work to methyl violet only. An aqueous solution of this was found to be preferable to solutions made up with different strengths of alcohol. It was further noted that the addition of sodium chloride to the dye solution introduced an improvement so far as clarification was concerned, but that a new difficulty was encountered in the form of an incomplete absorption of the dye by the soil. With increasing amounts of soil, the rate of removal of the dye fell relatively suddenly at a sudden point, but there were perceptible amounts of colour left unabsorbed in the solution even when the soils had been added in excess. These points are worth further study, which is hoped to be continued.

Observations were next made in which the process of absorption took place in stationary columns of soil. In some, the absorption was allowed to proceed from

below, the soil columns being packed in short lengths of open glass tubes, which were closed at the bottom with fine cloth or with filter paper. The tubes were placed over vessels containing dye solutions, with the bottom of the soil columns just a little below the upper surface of the dye solutions. It was found that the process is extremely slow. Even after 3 weeks there was not an appreciable upward movement of the dye into clay soils. With soils of a coarser nature, it was noted that after the water had risen to a short height, there was a tendency of the column to break at that level.

The next experiments included downward percolation of the dye solution through soils. Even with soil columns one inch in height, there was a liability of change of tint with certain soils and often sediments passed through the wire gauze at the bottom of the column. The absorption is not uniform throughout the soil depth, the precipitation being most heavy in the top layer, so that the first appearance of colour in the percolate is influenced not merely by the amount of soil but also by the height of the soil. The packing should be carefully done, avoiding fissures and also taking care that the soil is not loose at the places where they are in contact with the walls of the glass tube, so that the absorption may proceed at an uniform rate and that strictly comparable results may be obtained. Percolation is very slow with clay soils. The rate is a little quicker in the case of coarser soils.

In an experiment with a solution of methyl violet being percolated through a column of sandy soil, which was carefully packed into a tube of paraffined paper, it was found that the extraction of colour followed the usual exponential formula which holds in the case of absorption phenomena. After a certain length of the top la had absorbed the maximum amount, the distribution of the dye fell off in a regı manner. This would be evident from a consideration of the following figures wl were obtained by an examination of the different layers into which the soil was up at the end of the experiment.

Depth in cm. . .	0-1	1-2	2-3	3-4	4-5	5-6	6-7	7-8
Colour units . .	23·15	6·25	3·85	2·50	1·67	*	1·11	1·0(

* Spoilt: a crack was noticed in this layer.

Chart 6 shows the distribution of dye noted in the above experiment. It will be noticed that with the exception of the uppermost layer, the log-log curve is a straight line.

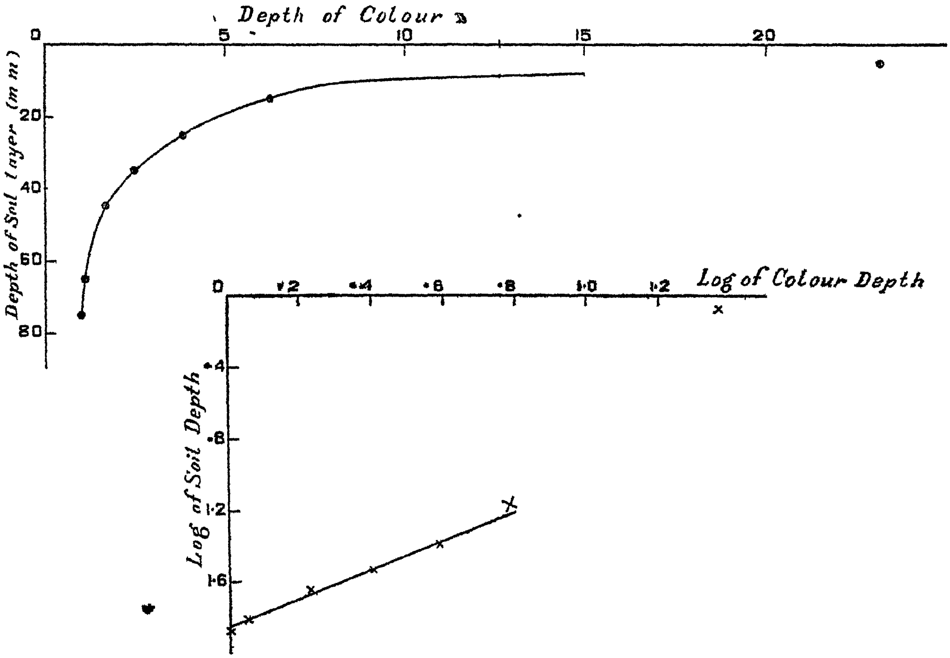

CHART 6.

Showing the absorption of methyl violet at different layers of soil column.

When the soil columns were long and the atmospheric conditions were dry, the slow passage of water through the soil and the rapid evaporation of the droplets of water which come out at the bottom gave rise to saline deposits o' fine crystals. This was noticed in the case of both a loam and a clay (calcareous Pusa soils). The crystals were found to contain chlorides, sulphates and carbonates. A study of this phenomenon is expected to throw light on the formation of soil alkali.

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